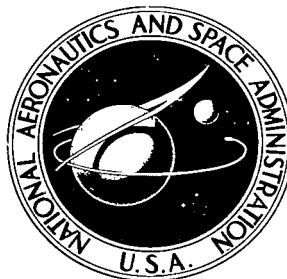


**NASA TECHNICAL
TRANSLATION**



NASA TT F-699

a. 1

NASA TT F-699

**LOAN COPY: RI
AFWL (DC
KIRTLAND A**

0069048



TECH LIBRARY KAFB, NM

TO

**TOWARD AN UNDERSTANDING
OF THE LAWS GOVERNING THE
DEVELOPMENT OF THE EARTH'S CRUST
AND THE GEOTHERMAL FIELDS
OF THE LITHOSPHERE**

by N. S. Boganik

"Nauka" Press, Moscow, 1970

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • FEBRUARY 1972



0069048

TOWARD AN UNDERSTANDING OF THE LAWS GOVERNING THE
DEVELOPMENT OF THE EARTH'S CRUST AND THE
GEOTHERMAL FIELDS OF THE LITHOSPHERE

By N. S. Boganik

Translation of "K poznaniyu zakonomernostey
razvitiya zemnoy kory i geotermal'nykh poley
stratifikatsii." Academy of Sciences USSR,
Scientific Council on Geothermal Research,
"Nauka" Press, Moscow, 1970

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the National Technical Information Service, Springfield, Virginia 22151

\$3.00



TABLE OF CONTENTS

	Page
ABSTRACT	1
INTRODUCTION	1
THE PROGRESSIVE DEVELOPMENT OF THE PROCESS GOVERNING THE FORMATION OF THE EARTH'S CRUST AND THEIR IRREVERSIBILITY	3
1. Geological Processes and Their Evolution	3
2. Magmatic Processes. Age Evolution of Magmatism Products	18
3. Causes and Factors Responsible for the Progressive Evolution of the Earth's Crust and the Emergence of New Laws in the Course of Its Development	28
PROCESSES OF RADIOACTIVE DECAY, THEIR CAUSALITY AND MEANING IN THE EVOLUTION OF TERRESTRIAL MATTER AND THE FORMATION OF THE GEOTHERMAL FIELDS OF THE LITHOSPHERE	36
1. Causality of the Processes of Radioactive Decay	36
2. A New Form of Nuclear Processes -- Processes Occurring Under the Effect of Natural Radioactive Radiation	47
3. Radiogenic Heat and Its Significance in the. Formation of the Geothermal Fields of the Lithosphere	60
CONCLUSIONS	74
REFERENCES	77

TOWARD AN UNDERSTANDING OF THE LAWS GOVERNING THE DEVELOPMENT OF THE EARTH'S CRUST AND THE GEOTHERMAL FIELDS OF THE LITHOSPHERE

N. S. Boganik

ABSTRACT: The book deals with problems relating to the progressive development of the processes involved in the formation of the Earth's crust, the causes and factors affecting the emergence of new laws during their development, processes of radioactive decay, and their significance in the evolution of terrestrial matter and the origination of geothermal fields.

This work will be of interest to geologists, geophysicists, geochemists, and other specialized personnel engaged in the study of the formative processes of the Earth's crust.

INTRODUCTION

/3*

The central problem discussed in this work is the problem of understanding the laws governing the formation of the Earth's crust. The discussion of this problem will be based on the geological and radiogeological data which the author has collected and analyzed over an extended period of time.

In the consideration of this problem a great deal of attention has been focussed on questions relating to the progressive development of geological processes and their irreversibility, as well as to the processes of radioactive decay and their importance to the evolution of terrestrial matter and to the formation of the geothermal fields of the lithosphere.

That these questions should be studied is of great importance at the present time in connection with expanded investigations into the deep-lying zones of the Earth's crust, studies of plutonic heat, and the development of scientifically founded methods for predicting the occurrence of mineral deposits hidden at great depths.

*Numbers in the margin indicate pagination in the foreign text.

The author is also of the belief that this work may be of assistance in the study of geoenergetic processes.

To Doctors of Geological-Mineralogical Sciences F. A. Makarenko, F. I. Vol'fson, and A. I. Silin-Bekchurin, the author wishes to express his sincere gratitude for their useful comments offered during their review of this work.

THE PROGRESSIVE DEVELOPMENT OF THE PROCESSES GOVERNING
THE FORMATION OF THE EARTH'S CRUST AND THEIR
IRREVERSIBILITY

/5

1. Geological Processes and Their Evolution

It is probably quite accurate to say that the principal source of our knowledge of the structure and development of the Earth is the Earth's crust. It is, in fact, the crust, widely accessible as it is to direct observation, that provides us with a vast amount of material for the elucidation of the processes and phenomena which have occurred on our planet.

The central task of the study of this crust, then, is to reveal the processes responsible both for its structural formation and for the formation and distribution within it of rock and mineral deposits. The very essence of this study consists in the revelation of the laws behind the development of the processes which have occurred on Earth and which have resulted in the origination and formation of the terrestrial crust as a natural-historic body.

The question as to what was the character of the processes leading to the evolution of the Earth and to the formation of its crust is one which has challenged the minds of scholars from the earliest times. Do these processes take place progressively, with the emergence of new laws, or do they in the course of time remain constant, manifesting themselves in one and the same forms of their being? Stated otherwise, have there been changes in the laws of nature and in the forces operative on the Earth as it evolved, and to what degree are those laws which may be valid for today's stage in the Earth's development applicable to the past study of its crust?

As indicated by the discussion of 1950-1951 [1] and by the theoretical conference of philosophical seminars on the actualism principle [1a], these questions continue to attract the attention of investigators. The explanation may lie in the fact that in the area of geology the investigator is confronted principally by concepts asserting a cyclical evolution of the historical and

/6

geological process¹. This view of the Earth's cyclic development dates back a very long time. The materialist ideas of Lomonosov, and later those of D. Getton on the eternal renewal of the processes taking place on the Earth, are closely interwoven with the view of the periodicity of these same processes. During the first half of the nineteenth century the predominantly accepted view was that of the "catastrophe theory," which sought to explain certain abrupt changes in isolated fauna, frequently encountered in geological layers, by catastrophes viewed as acts of "God." A reaction to these ideas was the appearance, in 1866, of D. Lysle's *Fundamentals of Geology*, which pointed to the possibility of invoking those same processes which are operative even at the present time to explain all the observable facts in the structure and development of the Earth's crust. Although, according to Engels, Lysle introduced a "common sense into geology" which was to be of great importance in combatting the catastrophe theory, nevertheless the acknowledgement of the constancy of the forces operative on the Earth led to the disavowal of the progressive evolution of geological processes.

Wide acceptance for the cyclical view of the development of these processes was won in the early twentieth century with the appearance of the works of Jolit, Augh and Shtille.

It is essential to keep in mind that while in any branch of science the investigative methodology plays a vital role, in the study of the laws governing the evolution of natural-historic processes -- the processes responsible

/7

¹ In the concept "cycle" we include that historically crystallized content which in geology has been most thoroughly and vividly expressed by Augh and Jolit and which consists essentially in the reduction of the Earth's entire history to processes which recur at specific intervals of time. Not infrequently the concept "cycle" is invested with the concept "rhythm," that is, the concept of the periodicity of a process accompanied by formations similar in composition and conditions of occurrence. Exemplifying such formations are the widely known strip clays of the Baltic, the flysch of the Caucasus and Carpathians, and others. These two concepts of cyclicity must be strictly distinguished. While the concept of cycle as the periodicity of an occurrence provides an objective portrayal of the process taking place, the concept of cycle as an evolutionary process does not represent the objective course of the development and in effect precludes any evolution by reducing it to a closed-cycle development.

for the formation of the terrestrial crust and the genesis of the Earth -- the aspect of methodology becomes quite paramount. Here the object of the investigation is above all the evolutionary process itself, and on the philosophic and methodologic bias with which the investigator approaches the study of this process will also depend the result of his inquiries, the depth and soundness of his scientific postulates and conclusions.

In our ever expanding understanding of geological processes, a role of enormous progressive significance belongs to the methodology of dialectical materialism, the methodology which constitutes the philosophical basis for scientific research and which is the guarantor of the triumph of Marxist-Leninist thinking toward the building of a Communist society on Earth. However, in the cognition of geological processes the victorious path of this materialist view leads through the direct and successful confrontation of metaphysical and mechanistic concepts of the evolutionary process. The field of geology, just as those of the other sciences, is the scene of an involved and hard-fought battle of ideas. In this battle the dialectical-materialist Weltanschauung and specifically Lenin's teaching on evolution provide a reliable compass toward a comprehension of the laws underlying the unfolding of geological processes.

Obviously, the problem of the character of the evolution of geological processes cannot be considered apart from one's general view of evolution as a whole. For this reason, it would be well at this point to recall the characterization of evolution (development) given by V. I. Lenin.

Lenin describes the two existing concepts of evolution in the following terms: "The two fundamental (or two possible? or two historically observable?) conceptions of evolution (development) are: evolution as reduction and increase, as repetition, and evolution as the unity of opposites (the dichotomy of what is one into mutually exclusive opposites and the interrelation between them).

"According to the first concept of movement, movement *itself* remains obscure, that is, its *motive* force, its source, its motive remain in the shadows (or else this source is transferred to something *external* -- God, a

subject, etc.). In the second concept, primary attention is centered precisely on the cognition of the *source* 'per se' of the movement.

/8

"The first concept is dead, pallid, sterile. The second is vital. *Only* the second provides a key to the 'automotion' of all that exists; it alone provides a key to the 'jumps,' the 'disruption of gradualness,' the 'conversion to the opposite,' the destruction of the old, and the origination of the new."¹

According to the concept of the cyclic evolution of the Earth, geological phenomena can be reduced to a cycle consisting of three consecutive phases: the accumulation of sediment, orogeny, disintegration, and removal. Disintegration and removal terminate the cycle, with the lowland formed as a result of removal sinking and becoming the scene of marine transgressions, leading to the accumulation of sediment and the beginning of a new cycle. In this way the cycle is closed. With this view, the "geological history of our planet" is nothing but the history of successive cycles. Each great cycle corresponds to a major division in the series of geological epochs" [2, p. 18]. Using the radioactivity of rocks, Joliet, it will be remembered, attempted to provide a physical justification for the cyclic point of view.

To make clear the methodological and scientific inadequacy of the concept of the Earth's cyclic evolution, the following definition of evolution given by Lenin is likewise of fundamental importance to us: "Evolution as the repetition of stages already traversed, but repeating them differently, on a higher basis (the 'negation of negation'); evolution, as it were, along a spiral rather than a straight line; abrupt, catastrophic, revolutionary evolution; 'disruptions of gradualness;' the transformation of quantity into quality; internal impulses toward evolution sparked by contradiction, the clash of various forces and tendencies of a given phenomenon or within a given society; interdependence and the most intimate, most indissoluble nexus of all aspects of every occurrence (with newer and newer aspects revealed by

¹ V. I. Lenin, *Polnoye sobraniye sochineniy* [Complete Collected Works], Vol. 29, p. 317 (Russian Edition).

history), a nexus providing a unified, regular, universal process of movement -- such are a few of the characteristics of dialectic as a more (than usually) substantive evolutionary doctrine."¹

/9

Comparing these two views of evolution, the insolvency of the cyclic conception, which fails to represent the entire multiformity of the Earth's evolutionary process, will be readily apparent. There is in it, for example, absolutely no place for the emergence of a new quality, of new laws both regarding the formation of the Earth as a whole and its crust in particular. The cyclic concept is at variance with the enormous wealth of factual material which has already been accumulated by geological experience.

Its scientific unsoundness may also be seen from the following data. We know that pre-Cambrian deposits contain large amounts of quartzite formations rich in iron ore; these include such major iron sites as Krivoy Rog, the Kursk Magnetic Anomaly, and others. In the deposits of later systems we know of no other reasonably significant formations of this kind. According to the cyclic concept, however, we should be able to discover, because of the cyclicity of the process, iron quartzite ore formations of the Krivoy Rog type to an equal degree in all the so-called cycles of geological history. But in fact this is not the case.

We know that deposits of the Carboniferous contain large quantities of coal beds, while in the deposits, for example, of the Silurian period such strata are unknown in any appreciable amounts; nor *can* they be discovered there in sizable masses for the reason that the vegetational world of that period was still at a very low stage in its evolution and could not provide the basic material for the formation of coal in the amounts that we encounter in the Carboniferous and subsequent systems.

Numerous other facts of this kind could be cited, and they would all contradict the concept of cyclicity. Such facts clearly demonstrate that the history of the Earth's development is not a cyclic, but rather a progressive one.

¹ V. I. Lenin, *Polnoye sobraniye sochineniy* [Complete Collected Works], Vol. 26, p. 55 (Russian Edition).

In the area of the crust's tectonic movements "diastrophic cycles" have been established, which are alleged to regularly control all the processes in the Earth's history. The regularity of the diastrophic cycle is derived from the observed alternation of states of relative calm with moments of more intensive movement in the crust.

Such phenomena, while they do attest to the non-uniformity of the evolutionary process, say nothing about its cyclicity. The principal facts on which this concept rests are the unconforming stratifications of folded formations.

In every individual case it will be readily discovered that each of the unconformably stratified formations differs in content: lithologic composition, sequence of constituent horizons, character of minerals, degree of crushing and shattering, different remnants of the organic world, nonidentity of geochemical processes related to the thickness of the formations and their compositions, presence of organic matter, and other essential attributes.

Instances of unconforming occurrences of crushed formations attest, as already noted, to an abruptness of development. In geology, abruptness, which constitutes one of the characteristic features of any evolution, is manifested in the interruption (disruption) of the gradualness of movement in individual regions of the Earth, in the occurrence of more intensive displacements in the crust, as well as in the severe alteration of the Earth's surface configuration and in a number of other phenomena. At the same time, these successive abrupt changes fail to disclose any noticeable constancy; on the contrary, they are extremely variegated both in their intensity and in their content (quality).

The reader is aware that efforts have been undertaken, based on rock radioactivity, to physically justify the concept of cyclicity. The line of reasoning here is as follows. All rocks are radioactive. As a result of decay, heat is generated which is accumulated in the substrate and causes it to melt. The result is a series of shifts in the Earth's crust, which give rise to cooling, which in turn generate new shifts.

It has been established by experimental data that the process of the radioactive decay of matter is subject to no cyclicity. The geological periods, to say nothing of the larger segments in the Earth's history which correspond to the so-called cycles, are interdifferentiated, among other things, by the additional fact that the amount of decayed matter will differ for them, and in every successive one of the Earth's periods there will be evident significant variations in rock composition and in the processes which take place in the crust under the effect of radioactive decay.

/11

It will easily be seen that undergirding the postulates we have been considering is a metaphysical understanding of the processes of the Earth's history.

With respect to the organic world, here there can be no question whatsoever of any cyclicity in its development. What does immediately strike the investigator is the emergence, during the course of evolution, of new species of plants and animals, and in this connection each so-called geological cycle reveals a progressively proceeding development. At the same time, the process itself whereby the organic world is renewed does not take place at the same pace in all segments of the Earth's history, but from time to time, as evidenced by paleontological data, discloses more abrupt changes constituting turning points and discontinuities in the general evolutionary development.

It would seem that the simple fact of the progressive development of the organic world would exclude any cyclicity in the geological process. But apparently the advocates of this view believe that the organic world exerts no significant effect on the behavior of so-called inorganic processes, or that changes are proper to the organic world, while from century to century nonorganic processes recur in the same forms. These assertions follow from the view that in by-gone eras the Earth was the scene of the same processes and phenomena which are witnessed in our present age.

In conformity with assertions of this kind we ought to suppose, for example, that the peat formation process in the pre-Cambrian was as extensively encountered as at the present time, or that the influence of the vegetational and animal world, as well as of man, on the transformation of the Earth's

surface has been identical throughout all geological periods -- which is, of course, absurd. However, according to the advocates of these theories, the formation of sedimentary rocks, their crushing into folds, metamorphization, injections of volcanic rocks, etc. -- in a word, all the so-called inorganic processes take place from century to century in exactly the same, very few and morphologically very simple, forms which bear virtually no imprint of the time, but carry almost exclusively the mark of their own formation.

/12

However, it is widely known that the ancient, pre-Cambrian rocks differ from later formations, along with other attributes, by their more pronounced metamorphization as well; we know that, all other factors being equal, rocks of the Cambrian and Silurian periods generally exhibit less pronounced metamorphization than pre-Cambrian, but more pronounced than later, say Mesozoic, rocks. This general principle is also not without exceptions: whenever young rocks are more markedly metamorphized than older ones. However, this kind of age relationship is rarely encountered.

Likewise unfounded is the assertion that nonorganic processes occur from century to century in precisely the same forms with respect also to the formation of sedimentary rock and its crushing into folds, along with certain other processes.

It is well recognized, for example, that the nature of folding and the tectonic disruptions of a specific region are manifested differently depending on the previous history of the region in question, while that same history for various regions affected by folding has not been the same. Folding is not some kind of "dead" form, independent of content; rather, this form is intimately related to content and reflects in its occurrence the whole wealth of diversity of this content. It would be incorrect to fail to take into account the differences in the forms in which folding has been manifested, as these forms have occurred during different phases of fold formation.

The very fact of the dissociation, in the study of the Earth's history, of what are referred to as inorganic processes from the evolution of the organic world is an example of a fallacious approach to the solution of the problem. This approach is inadmissible for the following considerations. In

the first place, by its activity the organic world is an important factor in the transformation of the Earth's surface. In the second place, by their concentrations the remnants of this organic world make up sizable portions of the rocks present in the composition of the Earth's crust (lime, coal, and others). In the third place, the presence of organic matter has a colossal effect on the evolution of geochemical processes.

/13

Using what has just been stated as a point of departure in the consideration of the lithological composition of the rocks occurring in the so-called cycles, it is clear that the organic world, beginning with its genesis, has undergone significant alterations; its effect as a transforming factor has varied from geological period to geological period; likewise, the role of the formations (limestones, coals, etc.), associated with the vital activity of the organisms and their relics, has also differed at different ages of the Earth's history. Similarly different have been the geochemical processes linked to formations of organic origin and to extensive strata of organic rock during different geological periods.

For example, the geochemical processes relating to coal formation in the Carboniferous were beyond question more significant than, say, during the Cambrian or Silurian. This follows from the evident fact that in the deposits of the Cambro-Silurian we fail to find any meaningful coal concentrations, at the same time that such concentrations are found in great abundance in the Carboniferous and later systems.

Of particular interest is the question as to whether upheavals and subsidences on geosynclines and platforms take place simultaneously or at different times and, correspondingly, whether in both places transgressions and regressions occur simultaneously or at different times. According to the cyclicity concept, transgressions on the platforms correspond to regressions on the geosynclines, with upheaval and subsidence occurring simultaneously on both. Synchronism and identity of movement on synclines and platforms constitute one of the cornerstones of the theory which, based on rock radioactivity and isostasy, holds that events in the Earth's history are repeated within large time intervals (150 to 300 million years). The sequence of the

events making up the cycle is this: slow subsidence accompanied by the encroachment of the seas on the continent, recession of the seas, and, finally, general upheavals.

Examining the factual material available on the question of crust movements, we are compelled to acknowledge that upheavals and subsidences on the platforms and geosynclines are not governed by the postulates described above. /14 Upheavals and subsidences on platforms and synclines occur in a variety of combinations: within a definite historical time frame both upheavals and subsidences take place simultaneously, with both occurring on platforms as well as in geosynclinal regions.

By way of example we might point out that the tectonic movements in the Quaternary period on the Eastern European platform and in the surrounding regions were of different character. In fact, the regions of Fennoscandia, the Azov-Podolsk Crystal Massif, the Donets Basin, and the Voronezh Block experienced upheavals during the Quaternary, while during the same period the areas of Polesk, the Danube Depression, the middle course of the Don, the lower reaches of the Kuban River and the basin of the Terek River, the lower Rion and Kura rivers, and the Caspian Depression underwent subsidence.

The available data make it clear that statements regarding the simultaneity and identity of character of the upheavals fly in the face of the factual material. In general, knowing how heterogeneous is the structure of the Earth's crust in individual areas, one cannot even assume that throughout the Earth's entire history the movements in it could be of identical character, that is, that both on the platforms and on the geosynclines they could be in the nature either of upheavals alone, encompassing the Earth's total crust (following the cyclic theory) or of subsidences alone, likewise of universal occurrence.

Such were the principal comments on the concept of cyclicity which we made in 1939 [3]. Over the last thirty years the cyclicity concept has been subject to repeated criticism by Soviet geologists. Still, until recently this view has remained in the arsenal of metaphysical ideas according to which the history of the Earth's crust and its surface is presented, as rightly noted

in the encyclopedia, "either in the form of a closed-circle cyclic evolution with return to the initial state (D. Jolit), or in the form of periodically recurring universal 'catastrophes' of fold formation or of orogenic phases separated by periods of quiescence (G. Shtille, L. Cobert, et al.)" [4, p. 520].

Even today certain notions of cyclic evolution find their way to the pages of our press. But at the present time it is not this school which forms the ideological basis of Soviet geological science. The view of dialectical materialism has won wide acceptance in Soviet geology. As early as the twenties and thirties this view exerted a profound effect on the development of geochemistry (V. I. Vernadskiy, A. Ye. Fersman) and of geotectonics (M. M. Tetyayev and others). At the same time there began to be cultivated in geotectonics the progressive trend widely known today as the "inheritance principle" (N. S. Shatskiy, A. V. Peyve, and others), according to which structural formation is viewed as a progressively evolving process consisting of two factors: inheritance and structural neogenesis [5].

/15

The view that the evolution of geological processes has been a progressive one is beginning to attain dominant status. The folding eras are already being considered not as the final links in a closed cycle repeated over extended intervals of time, but as definite stages in the evolution of the Earth's crust.

The major eras of folding have been given an entirely different interpretation. According to this view, the major folding eras make it possible to break down the evolution of the crust into a number of important stages -- metastages -- which represent the "sequence in the existence of definite types of major structural forms replacing each other in time and tracing, as it were, the principal steps on a given evolutionary path" [6, p. 27].

We might note that at the present time any more or less significant new fact derived from the study of the geological structure of the Earth's crust or the geology of the ocean floor acquires special significance toward an understanding of the laws of geological evolutionary processes.

Of great importance in this regard are the investigations into the material composition of lithographic records of the Russian Platform. Relying heavily on "measure and number," these investigations provide a basis for judgements, based now on quantitative data, regarding the geological development of this vast area. By summarizing this material it has been possible to determine the change over time in the relative dissemination and composition of the more important rock types on the Russian Platform [7-9] and, by generalizing Soviet and worldwide information, to formulate a well-founded picture of the evolution of the Earth's crust [10], the evolution of the composition of the Earth's solid shell, the ocean, and the atmosphere [11] from the early pre-Cambrian to the modern era, uncovering the causal relationships between the development of these Earth envelopes, variations in the composition of magmatic rocks, and the history of tectonic movements. An important point here is that it is precisely these factual quantitative and qualitative data on the simultaneous evolution of the lithologic composition of sedimentary rock, the cationic composition of the waters of the world ocean, and the gaseous composition of the lithosphere, hydrosphere, and atmosphere, accompanied by concomitant changes in the composition of eruptive rocks and by the evolution (due to melting and degassification) of the upper mantle, which constitute a convincing proof of the irreversibility of the processes which have occurred on the Earth during the entire time frame to which this factual information relates -- that is, from the early pre-Cambrian to the contemporary age. /16

In recent decades a large body of factual material has been developed regarding the Asian continent, with the analysis of this information leading to new and fundamentally important thinking. In the view of A. L. Yanshin, the new data "support the assertion that the structure of the Earth's crust shows a purposeful development and that the character of the tectonic processes in the Earth's history undergoes irreversible change [12, p. 11]. It is established that "tectonic processes have varied qualitatively over time. Geosynclines which existed at different periods in the Earth's history have differed in their morphology, magmatism, the formational character of sediments, and in the duration of their existence. Correspondingly, the folded structures which have arisen in different ages have also been different" [12, p. 30].

A. L. Yanshin writes further: "We must evidently regard as incorrect the widely held view of repetitive 'cycles' of geosynclinal development and folding, approximate in character and, moreover, of an approximately identical duration of 150 million years. In reality, no such cycles exist and one can speak only of evolutionary crust stages qualitatively differing in duration" [12].

In Yanshin's report [13] an analysis of the tectonic evolution of the Earth's crust is given and specific examples are cited to indicate the appearance of new structural types during the course of this development.

/17

In other areas of geological research also, in recent years, fresh data have been obtained confirming the progressiveness of evolution in geological processes. This information shows that the manifestation of gravitational forces on Earth has not remained constant; there have been changes in the position of the Earth's axis of rotation and of the poles, with corresponding variations in the manifestation of geological processes. Persuasive proof has been offered [14] to the effect that climatic zonality, the distribution pattern of rocks of specific lithologic composition, and the paleogeographic conditions inherent in the agglomeration of sediment have undergone profound changes over time. It must be particularly underscored that, during the course of these modifications, new distinctions emerged in the character of the sediment formation process itself, as occasioned by the irreversibility of the evolution of the physical-geographical environment and chemical-biological sedimentation [15]. An essential point is that these differences in sedimentation have been established with respect to the sediment accumulation of the post-Cambrian. There is no question but that the distinctions will be even more striking for the pre-Cambrian, whose history in this regard has thus far been little studied. Of paramount importance to this study are the fresh data [16] which indicate that pre-Cambrian formations consist mainly of metamorphic series of primary sedimentary and not magmatic origin, as has heretofore been believed. Also of particular interest in this regard is the latest information [17] according to which the most ancient lime relics of organisms date back to the archaic period and that life has existed on Earth for no less than three billion years. There are also compelling reasons to

believe that many carbonaceous rocks and iron ores of that period were formed with the participation of bacteria [17]. Radiogeological analyses of these ancient formations and of their synchronization are destined to play a vital role in the determination of the particularities of the geological history of the pre-Cambrian [18].

Available data on terrestrial magnetism indicate that over the course of the planet's evolutionary history the Earth's magnetic properties have not remained constant. This assertion flows from the fact that in various portions of the globe certain rocks exhibit a magnetic state oriented in opposition to the direction of the Earth's contemporary magnetic field [19].

/18

The possible occurrence of reverse magnetization can be explained by the assumption either that the direction of the Earth's magnetic field was opposite to its present direction at the time the rocks were magnetized, or that the rocks possessed some internal, physical, or chemical mechanism which caused a polarity reversal in its magnetism [20]. By way of example, one might mention that rocks formed beginning with the Upper Carboniferous and ending with the Lower and Middle Permian exhibit reverse polarity. These rocks have been documented on virtually all continents and span a time frame of 30 to 40 million years dating back to an era thought to be 300 million years in the past [20].

Other processes which have not remained constant on the Earth involve the effect of nuclear forces. The appearance of radioactivity has had the most profound possible influence on all aspects of life on our planet -- a fact which was noted even by V. I. Vernadskiy, the pioneer of radiogeological studies in our country. According to Vernadskiy, radioactive decay promotes perceptible changes in the planet's atomic composition and in its active energy. "Chemically speaking, our planet today and the same planet two billion years earlier or later are two different bodies" [21, p. 225].

Although these views, in the opinion of many scholars, may "require correction" [22, p. 218], there is little doubt that they portray a general progressive development in the composition of terrestrial matter. It is important to note that as time goes by, new areas are being discovered in

which natural radioactive emissions have influenced variations in the isotropic composition of terrestrial matter. For example, based on the study of data relating to the nature of nuclear reactions caused by natural radio-radiation, it has been determined [23] that under the effect of this radiation there occur in the Earth's crust transformations of the atomic nuclei of such abundantly encountered elements as silicon, potassium, sodium, magnesium, and others.

On the other hand, more significant changes in the geological processes of the stratisphere are associated with the heat released during radioactive decay. Moreover, the value of this radiogenic thermal factor has not remained constant over the passage of time. According to the calculations of G. V. Voytkovich, three billion years ago K^{40} released 5.3 times, and AcU^{235} 18 times, more radiogenic heat than at present [24]. It can be easily imagined -- and there is confirmation in geological data -- that in ancient times magmatic activity was far more intense than today, and, as research has indicated, the composition of the products of this activity have undergone evolutionary changes.

The progressive development of geochemical processes emerges with the utmost vividness, to the degree that this has given rise to the discipline of historical geochemistry, the problems of which have been discussed in the works of V. I. Vernadskiy, A. Ye. Fersman, and, in the most recent decade, A. P. Vinogradov [25], A. A. Saukov [26], A. B. Ronov [11], Yu. P. Trusov [27], and others.

It is worthwhile noting that one of the key aspects of our modern geological science, and one that plays an important forward-looking role in the inculcation of a proper understanding of natural-historic processes, consists in the fact that this science develops and consolidates the view of the Earth's history and the evolution of its crust as a progressive and irreversible process. This view has been brilliantly put forth in the work of Ye. V. Shantser. According to his definition, the history of the Earth is a progressive process during which there are qualitative changes both in its structure, the physical state of its matter, and the entire thermodynamic and

/19

physical-chemical situation in its core and on its surface. All this is accompanied by corresponding alterations in the conditions and very course of its geological processes [28, p. 106].

One is persuaded that such a definition of the Earth's history is in keeping with the modern state of the art in the evolutionary history of our planet.

2. Magmatic Processes. Age Evolution of Magmatism Products

/20

Magmatism is expressed in an intricate complex of eruptive rocks which constitute an integral part of the Earth's crust and are accessible to direct observation. As far as it is possible to judge on the basis of the abundance of eruptive rocks during different geological periods, as well as data regarding volcanic activity at the present time, magmatism has manifested itself differently in the course of time, both in terms of its intensity and the character of its eruptive products, on the one hand, and its coordination (association) with specific segments of the crust, on the other. This difference in magmatism comes to light in the dual nature of eruptions (intrusive and effusive type), in the multiplicity of the groups and kinds of eruptive rock, and also in the variety of their material composition and structure.

The principal factors responsible for the diversity of magmatic rocks include the layer-by-layer differentiation of matter, and time. The density of the mass, as expressed in the specific weight of the matter, is an important factor in its differentiation by layer during the process of the formation of our planet's envelopes and in the stratified distribution of matter in the lithosphere.

Inasmuch as the phenomenon of magmatism represents a complex process whereby matter moves from lower-lying zones to upper, the significance of specific weight must be recognized as a constantly operative factor in the distribution of the material composition of the magma, as evidenced in one way or the other both in the composition and structure of the eruptive rock.

The time factor in magmatism is of special importance. In a certain sense, magmatism is a function of time. This follows from the premise that

the Earth's crust originated at a particular stage in the evolution of our planet and that, in the course of time, it took form, increasing in volume and changing in structure. Crust thickening takes place because of the introduction of matter from the mantle into the lithosphere and, possibly, with the simultaneous accretion of the crust from below. Both situations are accompanied by a transition of the matter into a different state.

With matter so differentiated on a layer-by-layer basis, in the earlier stages of magmatism its upper, and consequently lighter, components must have shifted to the crust. With the passage of time, the role of the heavier components, brought up from the deeper-lying portions of the planet, are seen as acquiring greater significance in the magmatism phenomenon.

/21

Of signal interest in this connection is the history of thinking regarding the dependence of eruptive rocks on their age. The first efforts to summarize the data on the chemism of eruptive rocks and to classify them date back to the first half of the nineteenth century (Scherer, Durochet, Bunsen, et al.). This was also the period of individual attempts to explain the relation of rock chemism and structure to the time of their formation. Of particular interest in this regard are the efforts by Elide-Beaumont (1847). It was the belief of this investigator that the structure of eruptive rocks could be used to determine which of them were formed during the Earth's maturity and which during its old age.

Notions as to the dependence of the appearance of magmatic rocks on the geological age of their formation are reflected in petrographic terminology by such concepts as paleovulcanic and neovulcanic rocks, neointrusions, as well as by the terms mesoliparites, mesoandesites, and others.

During the second half of the nineteenth century the concept of rock structure as a function of formation age was intensively developed by the celebrated petrographer Michel-Levi (1872-1875). Comparing the structure of granites, porphyries, and trachytes with their age, this scientist recognized age to be the cause of the diverse structure of magma having identical composition, since, in his view, with the passage of time the amount of mineralizers in the magma becomes smaller and the crystallization conditions less favorable.

It is worthwhile noting that somewhat later (in 1889) Michel-Levi propounded a different viewpoint, holding that the classification of eruptive rocks should be based on structure and mineralogical composition, rather than on age and conditions of occurrence.

Not without interest are the views of Bregger (1894) who suggested that the terms "paleovulcanic" and "neovulcanic" (which imply age-related concepts) as applied to rocks be replaced by the terms "paleotypic" and "cainotypic", to stress not the difference in age, but rather the degree of preservation as a function of existential conditions (that is, with a centering of attention on the difference in the alterations of effusive rocks which arise after their formation).

/22

Side by side with viewpoints which in one form or another acknowledge a relationship between differences in eruptive rocks and their age, there have also been cultivated theories which take the opposite approach and deny this relationship, excluding the age factor from the classification of these rocks. This view was expressed by Dana as long ago as 1836, and was subsequently held by Chermak (1869), Olport (1874), Jedd (1885), and others. In our country it found supporters in Venyukov, Polenov, and others. These researchers all proclaimed the identity of ancient and young eruptive rocks.

Particularly intriguing are Daily's views, developed following a detailed study of eruptive rocks. Within a single vast area of magmatic activity Daily establishes various petrogenic cycles reflecting the recurrence of eruptive rock groups. He holds that in the first era as well as in the last the eruptions have been of essentially the same nature, with approximately the same ratio maintained for individual rock types within the petrogenetic cycles. Thus, he observes that the basaltic extrusions, in addition to being the most common, are also of the greatest average volume in any of the major geological time divisions.

Daily's general conclusion may be summarized as follows. Qualitatively intermittent magma eruptions generally tend to proceed in the same direction. With respect to the chemical diversity and character of the eruptions, observed pre-Cambrian, paleozoic, and mesozoic bodies are in many ways similar to

tertiary bodies [29, pp. 52, 53]. Daily admits exceptions from this postulate: a) extremely intense magma activity in the pre-Cambrian; b) the synchronization of all major anorthosite masses with the pre-Cambrian period; c) the specific development of quartz-poor, alkali-rich rocks and granodiorite groups in the post-Cambrian period.

/23

In this way we see that regarding the problem of the age-associated change of magmatic rocks a variety of opinions have been proposed which can ultimately be reduced to two fundamental positions of principle. One of these accepts the fact that over time magmatism and its products in one form or another experience change. Those who hold this view are inclined to link the cause of rock change with the age of the rock formation. According to the other viewpoint, magmatic eruptions show a general tendency to proceed in one direction, and to a significant degree such eruptions are of the same nature in the first era as in the last.

There can, however, be no doubt that both in time and in individual segments of the Earth's crust magmatic manifestations have been different and that this difference has been caused by changes, in the course of time, in the role of the individual elements in the makeup of the magma.

For the purpose of shedding light on the chemical difference in granite age groups the author has analyzed data on their material composition [30]. Average data for the granites are given in Table 1 for three groups: pre-Cambrian granites for 47 analyses, post-Cambrian granites for 184 analyses, and granites for "all periods" for 546 analyses.

The average values cited should, ideally, correspond to the mean percent content of individual components for the appropriate granite age groups. Naturally, the greater the number of analyses, the closer the average quantities will be to the real mean content; however, the analysis quantities actually presented can be regarded as generally reliable for preliminary conclusions. Although for the pre-Cambrian quantities the number of analyses is relatively small, still we are also able to judge the constancy and consistency of the average content by comparing it with the average figures for the "all periods" granites, for which 546 analyses were taken.

/24

TABLE 1. GRANITE COMPOSITION DATA BY AGE GROUP

Com- ponent	Granite			Com- ponent	Granite		
	Pre- Cambrian 47	Post- Cambrian 184	All Periods 546		Pre- Cambrian 47	Post- Cambrian 184	All Periods 546
SiO ₂	71.56	70.28	70.77	MgO	0.59	1.09	0.89
TiO ₂	0.48	0.34	0.39	CaO	1.98*	2.22**	2.01
Al ₂ O ₃	14.20	15.10	14.59	Na ₂ O	3.26	3.31	3.52
Fe ₂ O ₃	1.47	1.63	1.58	K ₂ O	4.53	3.98	4.15
FeO	1.65	1.67	1.79	P ₂ O ₃	0.10	0.27	0.19
MnO	0.18	0.11	0.12				

* Including 0.08% BaO and 0.01% SrO ** Including 0.06% BaO and 0.02% SrO

In fact, if in actuality there is some definite age-dependent law in the change of the material composition of the granites, then generally we should expect that the values for the granites of all periods will assume a mean position between corresponding points for the pre-Cambrian, on the one hand, and the post-Cambrian granites, on the other.

As can be seen from the analysis of these data, the values characterizing the percentage content of oxides for the "all periods" granite group do occupy such a mean position, with the exception of sodium oxide and ferrous oxide, for which these quantities are greater than their expected value. Very likely, for these components the average figures for 47 pre-Cambrian analyses and 184 post-Cambrian, making up less than half the total number of analyses for the "all period" granite group, do not fully represent the mean sodium content in the granite of the corresponding ages. We have reason to expect that corrections will evidently be in the direction of an increased mean sodium content for the post-Cambrian granites; this follows from the tendency for the sodium content to increase as the age of the granite decreases. The same statement also applies to the ferrous oxide. With respect to the remaining components, the average quantities show good coordination.

In considering these data, a principal point to note is that the percentage content for the oxides differs for the various granite age groups, with the content of some oxides in the post-Cambrian granites increasing, while in

/25

others, conversely, it falls. The variation in component content differs: for silicon it is expressed as 1.28%; for K_2O , Na_2O , CaO , MgO , Fe_2O_3 in tenths of a percent; and for MnO and FeO in hundredths of a percent.

TABLE 2. CONTENT OF ELEMENTS IN THE GRANITES

Element	Granites			Element	Granites		
	Pre-Cambrian	Post-Cambrian	All Periods		Pre-Cambrian	Post-Cambrian	All Periods
K	3.76	3.30	3.44	Si	33.42	32.82	33.05
Na	2.42	2.46	2.61	Al	7.51	7.99	7.72
Ca	1.41	1.59	1.44	Ti	0.29	0.20	0.23
Mg	0.36	0.66	0.54	Mn	0.14	0.08	0.09
P	0.04	0.12	0.08	Fe	2.22	2.44	2.39

Table 2 lists the content of individual elements obtained by converting the percentage content of oxides according to the atomic weight of the elements. By comparing the percentage content of elements by granite age groups it is possible to draw conclusions regarding the directivity of their content change in rocks of different age. Such a comparative analysis by age groups led to the following findings.

Potassium. The average potassium content in the pre-Cambrian granites is 0.46% higher than in the post-Cambrian; its average content in the "all periods" granite group is 3.44%. Therefore, the potassium content reveals a definite tendency to decrease along with the age of the rocks.

Sodium. The average sodium content in the pre-Cambrian granites is 0.04% lower than in the post-Cambrian; its average content in the "all periods" group is 2.61%. There is a clear tendency for the sodium content to rise as the geological age of the group decreases, that is, a tendency markedly in opposition to the behavior of potassium¹.

¹ It is interesting to note that similar contrasting tendencies and variations in potassium and sodium content have been established in the clays of the Russian Platform. There has been discovered, a gradual, more-than-two-fold decrease in the clay potassium content and some sodium increase moving upward along the lithographic section of the scale, that is, from ancient Riphean (sinic) to young tertiary clays [7]. Evidently, the causes responsible for the definite age-related directivity in the change in the potassium and sodium content in the granites and the directionally analogous changes of these elements in lithographic record of clays of the Russian Platform are the result of general evolutionary tendencies in the material composition of the Earth's crust.

Calcium. The average calcium content in the post-Cambrian granites is 0.18% higher than in the pre-Cambrian, with the average content in the general group at 1.44%. What is revealed is an evident tendency toward a greater calcium content in the granites as their geological age decreases.

Magnesium. The magnesium content in the pre-Cambrian granites is approximately 50% of that found in the post-Cambrian group (the absolute figures are, respectively, 0.36% and 0.66%). The general tendency of magnesium is the same as that of calcium: the content increases as the age decreases.

Phosphorous. The phosphorous content in the pre-Cambrian granites is about 25% of its value in the post-Cambrian group. The overall tendency is toward a considerable increase in the phosphorous content with declining geological age.

Silicon. The silicon content in the pre-Cambrian group is 0.6% higher than in the post-Cambrian granites. The tendency is toward a lower silicon content as the age of the granites decreases.

Aluminum. The aluminum content in the post-Cambrian granites is 0.48% higher than in the post-Cambrian; in the general group it equals 7.72%. This points to a tendency to increase as the age of the granites falls off.

Titanium. The titanium content in the pre-Cambrian granites is 0.09% higher than in the post-Cambrian; in the general group the average content is 0.23%. There is a rather clear tendency toward decreasing titanium with younger geological age of the granites.

Manganese. The manganese content in the pre-Cambrian granites is 0.14%, while in the post-Cambrian it equals 0.08%, the figure being 0.09% in the general group. Manganese content in the granites falls off as the geological age decreases; in all likelihood, the granites closest to the mean value in manganese content will be the paleozoic.

Iron. The iron content in the pre-Cambrian granites is 2.22%, in the post-Cambrian 2.44%, with an average value for all periods of 2.39%. There is a pronounced tendency toward increased iron content as the age decreases, with the necessary observation that in the general group the iron content occupies an average position between the age group values, a point which (as in

/27

the case of the other elements save sodium) serves as a reliability criterion for the average content of the granites we have cited.

From these data it will be clear that the tendency toward change on the part of the content of the various elements is of differing directionality. What is found is that as the age of the granites sinks, the percent content of potassium, silicon, titanium, and manganese falls off, while that of sodium, calcium, magnesium, phosphorous, aluminum, and iron increases.

The tendency toward change in the content of the individual elements is well expressed by the quantity describing the ratio of their content in the pre-Cambrian granites to the content in the post-Cambrian. For the elements in question this ratio is as follows:

K	Na	Ca	Mg	P	Si	Al	Ti	Mn	Fe
1.14	0.98	0.88	0.54	0.36	1.02	0.94	1.45	1.75	0.91

Based on this series of figures it is possible to judge the degree of aging change in the content of the individual elements. For the elements whose content falls off with decreasing age the ratio will be greater than unity, and, conversely, for those whose content increases with a reduction in geological age it will be smaller than unity.

It is of interest to note that the tendency discovered in the age-related evolution of the material composition of the granites is in excellent agreement with the theory of the melting out of light elements from the upper portion of the mantle [31]. According to this hypothesis, with insufficient removal of the heat released during radioactive decay, the upper portion of the mantle is partially melted and gives rise to a separation of elements. Given the high pressures and temperatures existing here, certain elements, forming stable minerals, remain in the depths, while others, transformed to a semiliquid state, rise upward. These components, having risen upward after separation, recrystallize near the surface into new mineral forms whose density is less than that of the minerals which originally contained these same elements and which were located, prior to separation, at greater depths. In this manner, sodium, calcium, aluminum, and silicon, combining with oxygen, form a comparatively light feldspar in the crust zone near the surface.

/28

In line with this hypothesis, in the course of time the sodium, calcium, and aluminum reach the crust from the mantle, corresponding to the results cited above for the aging analysis of the granites; apparently, with respect to silicon this process is of minor significance.

Of great importance toward an understanding of the laws governing the spatial distribution of magmatism products are the data on the dissemination of magmatic rocks for individual regions of the territory of the USSR and on the correlation of certain rock types within these regions. These data are to be found in the definitive work of S. P. Solov'yev [32]. Because of the importance of this information to a proper comprehension of the magmatism phenomenon, the pertinent data are summarized concisely below.

In their overwhelming majority, intrusive magmatic rocks within the territory of the Soviet Union are represented by granitoids. The areas of emersion of acid intrusive rocks is almost 19 times greater than the emersion areas of all the other intrusions taken together. The ratio of acid to basic rocks for the entire USSR is 22:1, although for individual regions -- for example, the Urals -- it is 1.4:1.

Among the acid rocks granites do not always predominate. Acid intrusions are by no means uniformly distributed in time. Basic and ultrabasic intrusive rocks are also distributed in the USSR in an extremely nonuniform manner. In the Urals, as compared to any other region of the USSR, they occupy more considerable areas. The ratio of acid to alkali intrusions stands at 122:1. Alkali intrusive rocks account for only 0.4% of the area of all other magmatic rocks.

/29

Among the effusive rocks, in most regions basic varieties predominate. The ratio of acid and basic effusive rocks is no less than 1:5. The basic effusive rocks are represented primarily by the basalts, which are widely developed in the eastern reaches of the USSR and in the Caucasus, comprising here more than 60% of the area of all other magmatic rocks.

The ratio of intrusive and effusive rock areas: for the Ukraine 1:80; in the young regions (for example, the Caucasus and the Far East) the area of

effusive rocks predominates over that of the intrusive. In the Caucasus the ratio of effusive to intrusions stands at 2:1, and in the Far East 3.3:1.

Note that even within the same period the processes of magmatism exhibit a progressive evolutionary development. In recent generations substantiation has been found for the view of magma complexes and magma formations as natural-historic associations of rocks. According to this view, on the path from plutonic intrusions to volcanic and subvolcanic (including also plutono-volcanic) associations, for each region a number of facies can be discriminated within the conditions of which specific magmatic massifs are formed, accompanied by metasomatic formations and corresponding to the phases of the deep-lying magmatic source [33]. At the same time, in the opinion of Yu. A. Kuznetsov, the rock association is to a large degree determined by the type and development stage of the geotectonic structure...[34]. G. D. Afanas'yev believes that any folded region has behind it a complex history of tectonomagmatic evolution. In a general case the contemporary appearance of the folded area represents a regular association of structuro-facial zones and subzones with which are coordinated concrete formations of magmatic complexes of different age [35]. It is not without interest, in this connection, to observe that even intrusions of identical age and type are accompanied by different mineralization depending on their disposition in different structuro-facial zones [36], and that there exists a causal nexus between different intrusive rocks and the differentiation of the melt at the magmatic focus and the processes whereby the magma is assimilated by the enclosing rocks [36a]. /30

The data cited above on the age-related evolution of the granites and the distribution of magmatic rocks within the territory of the Soviet Union support the conclusion that magmatic rocks and their complexes are not merely formations of a definite material composition in the lithosphere, but also the products of its natural-historical development which have undergone alterations in composition and structure in line with the general development of the Earth's crust and the evolution of its material composition.

From these statements it is clear that the fresh data which have come to light in various Earth science disciplines substantiate the progressive

character of geological processes and the emergence of new laws during the course of their evolution, with these laws in agreement with the dialectical materialist view of the course and development of natural processes and phenomena.

3. Causes and Factors Responsible for the Progressive Evolution of the Earth's Crust and the Emergence of New Laws in the Course of Its Development

In order to understand the causes and factors responsible for the progressive evolutionary course of geological processes, bearing in mind here all those processes and forces of nature through the instrumentality of which the formation of the terrestrial crust has taken place, one must proceed to the consideration, in a broader context, of the problem of how the basic forces of nature are displayed and operate.

It would appear that we have sufficient basis for an examination of this kind since the chief object of the study of geology -- the Earth's crust -- carries within it the information required to shed light on this problem. Perhaps to a greater degree than the other natural sciences, geology has at its disposal facts capable of illuminating the question of the character, manifestation, and operation of those fundamental forces of nature under the effect of which the Earth's crust has been formed, that same crust which in its structure and evolution portrays the functioning of these forces and which, thus far at least, is the sole celestial body accessible on a wide scale to immediate study.

/31

In point of fact, the geological formations present in the composition of the terrestrial crust arose and were formed during the evolution of the Earth itself. A significant portion of these formations have existed for billions of years and are commensurate in time with the duration of the life of the planets and stars of the Universe. These geological formations carry information on the conditions and sequence of their own origination and constitute a source of knowledge regarding the evolution of terrestrial matter and the conditions underlying the genesis and development of life on Earth. They are likewise a source of understanding of the natural laws governing the development of our planet, the formation of its structure, and, in particular, the

establishment of its crust, providing a basis for conclusions as to the variability of these laws in the course of time.

Above all, geological formations allow us to judge the character of those laws under whose influence these formations came to light. They present the student with factual material to determine to what degree the principle of actualism may be valid.

The idea that contemporary processes occurring on the Earth are the key to an understanding of its past can be traced back to very remote times. In the past century this motion was forcefully expressed in the works of Ch. Lysle, in whose *Fundamentals of Geology* the thought is advanced that the action of those laws of nature which can be observed at the present time is sufficient to explain all previous phenomena which have transpired on the Earth.

"Many phenomena," writes Lysle, "which for a long time were considered proof of some mysterious, unusually operative cause have been finally recognized as the necessary consequence of laws which presently govern the material world...; in the course of those centuries which are contemplated by geology there has been no interruption in the activity of the same constant laws of change" [37, p. 69].

Assessing the works of Lysle, Engels noted: "Lysle alone has introduced common sense into geology, replacing the sudden caprices of some revolutionizing agent with the constant action of the slow transformation of the Earth... The deficiency of Lysle's view is his belief that the forces operative on the Earth are constant..." [38, p. 12].

/32

As indicated above, the actualism principle continues to draw the attention of scholars. This may be explained, in our opinion, by the fact that the actualism principle is a particular expression of a broader view of the immutability of natural laws in general. Such views are widely held in the modern natural sciences.

At the present day, even among those scholars who adhere to materialist positions and acknowledge the objective existence of natural laws, a variety

of theories are entertained regarding the nature of the action of these laws. Of paramount interest among them are two fundamental points of view.

According to one of these two viewpoints, the laws of nature "...recur with identical precision and inevitability both on the Earth and in the Universe" [39, p. 12]. And "the laws governing these occurrences on worlds situated even in the remotest nebulae are the same as on our planet Earth" [40, p. 4]. The immutability of these laws in time is also affirmed: "Although nature is in a state of constant change and evolution, the laws of this evolution suffer no change and were the same billions of years ago as they are today" [40, p. 4].

According to the other view, the laws of nature, as also the specific forms of the movement of matter, are transient, relative, historically and locally circumscribed. This position has been brilliantly expounded in an interesting work by V. I. Sviderskiy, *"Dialekticheskiy materializm ob obshchikh Svoystvakh Dvizhushcheyasya Materi"* [Dialectical Materialism on the General Properties of Moving Matter]. Sviderskiy writes: "Recognizing the relativity, the circumscribed and transient character of the specific forms in the movement of matter, we must also regard as relative the specific laws of this movement as well. It is of this nature -- relative, historically and locally limited -- that we are to consider the physical laws (not to mention the laws of organic nature, psychic processes, or social phenomena), such as, for example, the mechanical, the thermodynamic, the electromagnetic, the gravitational, and the rest. There can consequently be no absolute, universal physical law, whether it be the law of gravitation, the law of increasing entropy, the law of the unity of chemical composition, or any other" [41, p. 15].

/33

It would seem that in considering the operation of the laws of nature, it is essential to take into account their spheres of influence and interrelatedness, along with the consequences which flow from their interaction. The available data on natural laws indicate that in the universality of their manifestation and operation these laws are different: certain of them are more universal and constant, others less, and there is no basis for believing that their effect is identically manifested on all the bodies of the cosmos and everywhere throughout the Universe through all of its existence. There is

equally no basis for the assertion that such laws, to the same degree as the specific forms in the movement of matter, are limited in space and in time.

In reality, some laws of nature are of limited effect and are manifested only in specific forms of matter and in specific forms of its movement, and they are just as transient as those very material forms to which the manifestation of these laws is proper. Among these laws are: the laws of mineral formation, of rock distribution in the Earth's crust, and numerous others -- that is, all those laws whose appearance is limited by specific conditions or by a definite material composition. Other laws are more universal and constant, being proper to a wider range of forms in the movement of matter within the Universe, and these might include the laws of gravitation, and to a lesser degree those of magnetism and of nuclear forces. Using as a point of departure what is already known concerning the manifestation and effect of natural laws on the individual planets, one cannot fail to conclude that these laws vary on different celestial bodies. Consider briefly the nature of their manifestation and operation.

Law of gravity and its operation. The correctness of Newton's law of gravity has been confirmed, as we all know, by centuries of observation and by the practical computation of the orbits of bodies and the possibility, on the basis of this law, of accurately predicting, for any preassigned moment of time, the relative positions of celestial bodies in space.

Although it is difficult to imagine that there is somewhere in the material world of the Universe a line or point beyond which the law of gravitation does not apply, still the history of our understanding of the surrounding world does indicate that our knowledge is relative and that often unexpected modifications are made of firmly established concepts as a result of newly discovered phenomena. This was the case with the behavior of light following the discovery of its dual nature (particle and wave); with the law of increasing entropy because of its inapplicability to living forms of matter; with the laws of classical mechanics when it became known that they do not apply to the microparticle world; and with others. Thus, although by

/34

all data the law of gravitation seems universal, nevertheless, since it has been empirically established, new phenomena revealing its limitedness may yet be unearthed.

While acknowledging the universality of the law of gravitation, we in no way support the view that its operation is identically manifested everywhere in the Universe and on all the planets, including the Earth. As evidenced by factual data, the effect of the gravitational law is expressed in various ways on different celestial bodies and leads to very different results.

The difference in the manifestation of the operative law of gravity on the planets has had a decided effect on the history of their evolution, on the formation of their structure and composition, and on the creation of conditions under which the emergence and development of life and the origination of a number of other planetary peculiarities has become possible (or impossible). Of great importance to the origination and formation of individual distinctions on celestial bodies, even those interrelated by common origin, was the magnitude of the mass of the body itself -- something that can be very graphically appreciated in the structural and evolutionary peculiarities of the Earth and Moon.

Thus, the very magnitude of the Earth's mass, which has been responsible for its force of attraction and the development around it of a definite gravitational field, has been of decisive significance in the formation of its aqueous and atmospheric envelopes with their colossal effect on the course of the processes and phenomena which come to term under the influence of water and atmosphere and under the effect of which geological formations came into being, terrestrial matter was developed, the vegetable and animal world on the Earth sprang up and evolved.

A vivid example of another specific effect of the law of gravitation is offered by the Moon. Because of its relatively low mass, the Moon's field of attraction was inadequate to retain the gases which appeared on its surface. For this same reason, no water envelope developed on the Moon. It was this absence of atmosphere and water on the Moon which determined the unique character of the rock disintegration processes on the lunar surface. In the

/35

absence of atmosphere the lunar surface has been severely heated by day and rapidly cooled at night, promoting intensive disintegration of rocks and the formation on the surface of unique disintegration products quite unlike the geological formations of the Earth. The Moon also lacks all those processes and phenomena which are linked to the life and activity of organisms. The absence of an atmosphere has likewise had a substantial bearing on the effect of meteorites on the lunar surface. Under terrestrial conditions, meteorites, as they approach the Earth's hard surface, encounter an atmospheric envelope, are intensely heated by friction, and their matter is vaporized. This process results in many of them being converted to vapors and gases so that in the solid state they do not reach the Earth's surface at all. On the Moon, on the other hand, there is nothing to prevent the meteorites from impacting.

In this way, the specific manifestation of the law of gravitation on the Earth and on the Moon is different. There is no doubt but that it is also different on the other celestial bodies as well, since their masses, too, are different. This difference in the operation of the law of gravitation is caused both by the magnitude of the mass and by the conjunction of the law's effect with the other factors and forces operative under the particular conditions appropriate to each individual celestial body.

Magnetism and its manifestations. According to the modern theory of magnetism, all micro- and macro-bodies possess magnetic moments and "in principle may be sources of magnetism" [42, p. 11], and in this respect the concept of magnetism as a "universal property of moving matter, related to structure" finds its justification [42, p. 3].

Although all bodies may give rise in surrounding space to a magnetic field and may be subject to the effect of external magnetic fields, in reality /36 by no means all natural bodies display magnetic properties. It is a known fact that only certain natural bodies possess the properties of permanent magnets. In line with the magnetism doctrine, this difference is explained by the fact that "permanent magnets differ from other bodies in that the molecular streams in them are oriented in an orderly fashion and thus provide a concerted magnetic effect in outer space" [42, p. 5], while in other

bodies these streams are chaotically distributed, with the result that their magnetic effects are neutralized and are imperceptible. Therefore, in this respect magnetism is not a universal property of matter and is manifested differently on different bodies.

A different manifestation of magnetism can also be established for celestial bodies. Thus, it was long ago determined that the Earth on the whole possesses magnetic properties and generates around itself a magnetic field. For a long time it was held that all the other planets exhibited such magnetic properties to an equal degree; however, space-probe investigations have shown that neither the Moon nor Venus have the kind of magnetic fields whose presence might have been assumed on the basis of what is known regarding terrestrial magnetism.

Available factual data indicate that magnetism is displayed by the different planets in various ways, and though it is still not known what causes this difference there is no question but that the presence or absence on a planet of a powerful external magnetic field -- or of magnetic belts surrounding it -- has a different effect on the behavior of numerous important processes and phenomena transpiring on it, such as, for example, the conduction of cosmic radiation and its density as generated directly at the planet's surface, the behavior of nuclear reactions on the surface, the planetary heat balance, and the like.

As indicated above, even under the evolutionary conditions of the same body the manifestation and operation of magnetism do not remain identical, but undergo substantive modifications in the course of time, a point that has been well established with respect to Earth.

Manifestation and operation of nuclear forces. Included among the basic forces of nature such as magnetism and gravitation, which have been long known to man, are the nuclear forces, of which he learned quite recently, but which have already shown themselves to be a powerful natural force source whose manifestation and operation has an enormous effect on nature and its entire evolutionary behavior.

/37

In terms of scale, the most important manifestational form of nuclear forces was discovered in 1939 (Bete), when it was proven possible that in the depths of the Sun and stars a synthesis of light atoms takes place, accompanied by the release of a large amount of energy, thus providing an explanation for how the Sun and stars are able to dissipate their energy for billions of years with no noticeable weakening.

Because of the thermonuclear reactions occurring within it, the Sun is the source of a variety of radiations. The data of modern space physics indicate that many geophysical phenomena are caused by the ultraviolet, X-ray, and corpuscular radiation of the Sun, which do not remain constant.

The manifestation of nuclear forces is proper only to certain atomic forms of material existence, and in this respect the manifestation and operation of these forces is not universal (cf. the forces of gravity). Normally, their operation in atoms remains externally imperceptible, being displayed only in individual nuclei in the form of radioactive decay. The manifestation of these forces in the form of the synthesis of atomic nuclei is proper only to certain celestial bodies in the stellar state.

From the data cited on the particularities in the manifestation and operation of the forces of gravitation, magnetism, and the nuclear forces it will be seen that under the specific conditions characterizing the existence of every celestial body there are operative, along with the working of the general laws, particular laws which, interacting with the former, modify them and determine the character and peculiarities of the governance of the local processes and phenomena transpiring on the body in question within the specific conditions of its being.

As a result, during the evolution of these bodies, and especially of the Earth, new laws are manifested which are responsible for the progressive element in the development of the processes occurring on the planets and, in particular, the historico-geological process on the Earth.

1. Causality of the Processes of Radioactive Decay

The discovery of radioactivity (1896) marked a milestone in the understanding of the structure of matter. It revealed the source of intra-atomic energy and laid the basis for the persistent search after ways to employ this energy in a practical way which was to culminate in the scientific successes of the forties of the twentieth century.

Not only did the discovery of radioactivity usher in radical modifications in the concept of the structure of matter, but it also triggered a veritable revolution in all areas of scientific inquiry by fundamentally changing our understanding of the nature of the most important phenomena.

It would seem appropriate at this point to recall the words of V. I. Vernadskiy, who more than a half-century ago placed high value on the role of radioactive phenomena in the unfolding of scientific knowledge. He wrote: "As we penetrate more deeply into the phenomena of radioactivity, their significance becomes more vital to us; every year sees the discovery of altogether unanticipated consequences of the study of these effects, consequences which are radically changing centuries-old, scientifically elaborated concepts... We are approaching ever closer to a rethinking and a restructuring of the time-honored foundations of scientific knowledge" [43a, p. 575].

Because of this discovery an entirely different light was shed on such problems as the source of terrestrial heat, the migration and distribution of chemical elements, the nature of orogenic processes and earthquakes, and other important questions directly relating to geology and other disciplines.

However, despite the astonishing achievements of the atomic physics of recent decades, certain widely held understandings of the process of radioactivity have been stalled on the level of the original research, when the atomic nucleus and the factors affecting its state were still unknown. One of the fundamental principles underlying this concept of radioactivity consists

in the view that natural radioactive decay occurs at the same rate, which is constant for each radioactive element and independent of its external conditions¹.

Thus, one can find in the special literature on the subject assertions to the effect that radioactivity is the sole process in matter over which we are able to exercise no control; that there is something supernatural in its isolation from the environment and in its indifference to it; that radioactive processes take place spontaneously, cannot be either accelerated or decelerated, and show absolutely no reaction to changes in physical and chemical conditions; that the rate at which a given radioactive substance decays is constant and independent of physical and chemical conditions; that by no techniques or magnetic fields at our disposal can we vary the rate of natural radioactive transformations.

All these assertions, which follow from the principle of the constancy of the radioactive process and its independence of external conditions, are in contradiction with the factual data of contemporary atomic physics and geology. They are at radical variance with the principles of dialectical materialism.

The principle asserting the constancy and independence of the radioactive process has had a negative effect on the development of the science of geology, which places precisely this principle at the heart of its understanding of a host of natural-historical phenomena. It underlies modern teaching regarding the distribution of radioactive elements, and on this principle rests one method of determining the absolute geological age of rocks and minerals, and the like. /40

The advocates of this principle argue that radioactive substances have been heated to high temperatures, subjected to great pressures, placed in powerful magnetic fields (as much as 83,000 oersteds), as well as in centrifugal fields with accelerations 20,000 times greater than g , and that despite

¹ This proposition has been criticized in detail by the author in a special article [44]. Its basic premises are cited here.

all these intensive manipulations no change in the rate of radioactive decay could be detected. Nor is this rate affected by the concentration of radioactive atoms: despite changes in concentration in the ratio of 1:2,000, the constant λ , characteristic of the transformation rate of the radon, retained its former value.

It is easy to see that this line of reasoning suffers from incompleteness and that it does not include occurrences of artificial radioactivity or the results of the study of cosmic rays -- precisely the area of factual data which does indeed demonstrate that radioactive decay is affected by definite external factors. While during the initial stages of thinking regarding the radioactive process as one that was constant and independent it might have seemed reasonable to believe that none of the affecting influences known at that time to science had any effect on the rate of radioactive decay, nevertheless from the moment of the discovery of artificial radioactivity -- and, to an even greater degree, the subsequent breakthrough in the field of nuclear physics culminating in the understanding of chain reactions -- any assertion that atomic decay is a purely individual event independent of external influences is simply not in agreement with established facts.

These views on the constancy and independence of the radioactive process were formulated during the first years of our century shortly after the discovery of radioactivity. They are based on the findings of experimental research obtained under definite, strictly limited laboratory conditions, which, as has now become clear, in fact precluded the detection of the relationship between the rate of radioactive decay and changes in temperature and pressure.

It was the data of these tests that generated the assertions that the behavior of radioactive decay is entirely independent of terrestrial fields and energy forms and of the natural forces known on Earth. These postulates regarding the independence and a kind of unnatural exclusivity mirrored in the conceptions rather than from the results of laboratory experimentation.

/41

It is altogether clear that the laboratory conditions under which the research into radioactivity phenomena was conducted during these first stages

failed to exhaust all the experimental possibilities or, far less, the natural factors which might affect the behavior of the process. Such experimentally derived observations permitted merely the limited conclusion that, under given conditions and employing given limited investigatory techniques, no change was detected in the rate of radioactive decay, but what was in fact drawn was the conclusion as to the unrelatedness of the radioactive process to any external factors whatsoever. It was a case of a broad conclusion failing to match a limited experiment.

Touching on the history of thought regarding the constancy and independence of the radioactive process, it is worthwhile noting that as early as 1915 the famous Russian chemist L. A. Chugayev, in an examination of the indifference of radioactive transformations to experimental conditions and to the "bias" of the experimenter, wrote: "It is possible that this absence of any kind of influence is merely a seeming absence and is caused by the circumstance that our methods of investigation are too crude to allow us to capture the infinitesimally minor effects which in fact do take place, or, on the other hand, that we may have been unable to concentrate a particular form of energy in sufficient measure for its effect on the radioactive processes to assume a perceptible magnitude" [45, p. 134].

Thus, this principle of constancy and independence had rightly been called into doubt, and even then it had quite properly been observed that the failure of external factors to affect the process of radioactivity is merely an apparent failure due to the imperfect nature of the research methodology. However, at that time this penetrating insight was not awarded the importance it merited.

We should recall that proper recognition was also not forthcoming for the discoveries of our geophysicists L. N. Bogoyavlenskiy and A. A. Lomakin, who pointed out (in 1923-1925) that the potential of penetrating radiation near the Earth's surface changes within wide limits and, apparently, bears a direct relation to the concentration of radioelements at the site in question [46].

/42

In opposition to all this, and based on statistical data derived from decay rate observations of isolated radioactive substances, the principle of

the constancy and independence of the decay of radioactive substances was elevated to the rank of a law, according to which any radioactive substance under any conditions decays in accordance with the formula $N = N_0 e^{-\lambda t}$, where N_0 is the number of atoms of the radioactive substance at a certain moment of time equal to zero; N is their number at the moment t ; λ is a constant describing the rate of decrease; e is the base of the natural logarithms.

This law, which is founded on statistical observations, was made central to the determination of the rate of the radioactive processes which take place under natural conditions. The law states that, during a period of time corresponding to the so-called half-life period, one half of the initial quantity of the atoms of a given substance always and under any external conditions decays, and that in the subsequent second half-life period one half of the atoms of the remaining half decay, with half of the remaining quarter decaying in the third period, and so forth -- that is, with the decrease occurring according to what is known as the exponential law.

It is perfectly evident that this formulation, underlying the exponential law and expressing the relationship of decay, assuming its rate to be constant, to elapsed time and to an initial quantity of atoms, is of particular significance -- that is, it is valid under definite conditions and namely those conditions for which it was statistically derived. It cannot be considered universal or applied to areas of the unknown.

Today, with our knowledge that the principal factors capable of affecting the decay of an atomic nucleus are neutrons and other elementary particles ejected by the nuclei as they decay, as well as cosmic rays, any such views as to the invariability and independence of radioactive decay as are based on considerations of a thermodynamic nature for relatively low parameters cannot be entertained as a persuasive argument in favor of the impossibility of affecting the decay by other factors.

/43

This principle is in contradiction with factual data: the results of the study of artificial radioactivity and the splitting of the atomic nucleus, research into the effect of cosmic radiation on variations in the isotopic composition of Earth elements, and geological data.

It is also known that under the effect of neutrons, protons, or alpha-particles atomic decay is accompanied by the formation of nuclei which are either isotopic with the initial nucleus or removed one or two steps in the periodic system, and that radioactivity is no longer an exclusive phenomenon of only a few elements: all the elements of the periodic system are subject to conversions, beginning with hydrogen and ending with uranium and the artificially created transuranium elements. The assertion that modern science knows of no means or methods to influence the behavior of the radioactive process is at odds with the facts of artificial radioactivity, which is generated precisely by the effect of external stimuli known and accessible to the modern scientist.

The discovery in 1938-1939 of a new kind of nuclear reaction in which, as a result of neutron capture, the initial heavy nucleus (uranium, thorium, protoactinium) is split approximately in half, also has its counterpart under natural conditions as well. This has been substantiated by the experiments of Soviet physicists [47]. It is important to note, in this connection, that with a decay of this kind, neutrons are released which, if conditions are favorable, in turn become the source of new fissions.

Of importance to the initiation of chain reactions are the mass of the radioactive substance, the form of the mass, the purity of the substance, the presence of neutrons and inhibitors (carbon, heavy water, beryllium, and others), although the reaction may proceed under the most conventional temperatures and pressures.

In nature, where processes of natural radioactivity occur, the mass dimensions of the concentrations of radioactive substances, the forms of these concentrations, the purity of the substances, as well as the concentration of neutrons, inhibitor substances, and also substances which may be the source of neutrons, protons, and α -particles, fluctuate and combine differently in each specific instance in which radioactive elements are found. We may reasonably expect that the rate of nuclear decay for each such instance will also be different.

/44

The investigation of cosmic rays has led to direct proof that under natural conditions there are factors which affect the course of natural radioactive transformations.

It has, for example, been established that C^{14} owes its origin to neutrons of cosmic radiation. When the neutrons are absorbed in the atmosphere, radioactive carbon is generated because of nitrogen N^{14} . The latest research confirms the formation of helium under the effect of cosmic rays.

Studies of nuclear transformations in glass under the influence of cosmic radiation have demonstrated the possibility that within a year's time in a single cubic centimeter of glass there will accumulate no less than 10^5 atoms of helium. The glass composition includes substances (SiO_2 , Na_2O , CaO , MgO) which make up the basic and most widely encountered parts of the lithosphere. There is little question that a portion of the helium found in rocks owes its origin to cosmic radiation. Experimental research has also confirmed the division of uranium (U^{235}) under the action of cosmic emission.

The principle of constancy and independence is pivotal to the radioactive method of fixing the geological age of minerals and rocks.

In the radioactive method of rock and mineral age determination this principle is augmented by yet another principle which asserts the possibility that during the passage of geological time there have existed unchanging external conditions under which the decay transpires -- that is, the kind of immutability of conditions which ensures the total preservation of each of the 13-15 elements formed in the major chain of transformations with different physical-chemical properties at the point of decay.

It is not likely that any such constant immutability of external factors, as is in principle postulated by the radioactive method, is actually observed. It would rather appear that the very inconstancy of conditions is one of the reasons for the instability of the age data derived through this technique.

It must also be pointed out that the end products of radioactive decay, on the basis of which the time lapse determination is made, are the function of a large number of variable quantities. Thus, the amount of end product in the decay of lead depends on the completeness with which are preserved all

/45

the substances (numbering as much as 15) formed in the long decay chain, beginning with uranium (or thorium) and ending with lead. Here it should be stressed that the intermediate elements formed, possessing different physical and chemical properties, are in a state of active interaction with a changeable external environment, amid which the process of decay is transpiring, and, consequently, to a considerable degree these intermediate products fall outside the limits of the mineral whose age is determined on the basis of residual radiogenic lead. This loss of intermediate and final decay products accompanies the entire protracted time (millions and billions of years) of radioactive transformations.

To be sure, the methodology for determining the absolute age of minerals has been perfected and a variety of improvements have been made in it. However, all these positive modifications have not succeeded in eliminating the fundamental premise of this method -- namely, the fact that the technique is founded on the principle of a constant rate of radioactive decay, on the independence of decay on external conditions, and on the assumption of the existence of constant conditions such as would ensure the total conservation of the initial, intermediate, and final products of the radioactive decay at the site of their formation throughout the entire history of the Earth's evolution.

One cannot but emphasize at this point that it is, above all, precisely in minerals containing radioactive elements that this kind of conditional constancy cannot possibly be, since the radioactive decay of these minerals breaks down the crystal lattice of the mineral and facilitates the departure of decay products to the outside. Consequently, a source of destruction is implicit in the process itself, not to mention the other conventional factors present in the disintegration of rocks and minerals.

Turning now to the widely held "theory" of the geochemical distribution of radioactive elements in the Earth, according to which it is postulated that such elements are concentrated in a virtually exclusive manner in the outer 16-48 kilometers of the terrestrial crust, the point to be noted is that this theory follows from a thermal balance of the Earth derived for a constant rate of radioactive decay, it being on this basis that the conclusion is

/46

drawn regarding the impossibility of encountering radioactive substances at subcrust terrestrial depths.

From this theory it follows that if radioactive elements were present in the deep regions below the crust in the same quantities as in the crust, the Earth would then have to be in a melted state, but since the Earth is hard, radioactive elements are absent beneath the 16-48 km envelope.

This conclusion flies in the face of the well known and firmly established fact that all the rocks forming the Earth's crust, among which there are unquestionably rocks of plutonic origin formed from magnetic foci at subcrust depths, do exhibit radioactivity.

The above view is also inconsistent with data on bathyseism which might be related in origin to radioactivity processes.

The concept of the constancy and independence of the radioactive process was formulated at the outset of the twentieth century. This was a period during which metaphysical conceptions held sway. These conceptions were the object of withering criticism by V. I. Lenin in his classic work [*Materializm i empiriokrititsizm*]. The physics of that time, it will be recalled, was in the grip of a crisis as time-honored dogmas were being discarded with the advent of new discoveries. The electron theory had undermined the most fundamental principles of physics, and physicists were proclaiming the "disappearance of matter" and the "dematerialization of the atom."

Reviewing the theories of the time, Lenin wrote: "'Matter is disappearing'-what this means is the disappearance of that boundary which has delimited our knowledge of matter until this time; what it means is that our understanding is becoming more profound. What are disappearing are those properties of matter which have previously seemed absolute, unchanging, original (impenetrability, inertia, mass, etc.) and which are now being revealed as relative and proper only to certain states of matter."¹

In light of these postulates of Lenin it will be easily seen that ideas regarding the constancy and independence of radioactive decay reflect an

47

¹ V. I. Lenin, *Polnoye sobraniye sochineniy* [Complete Collected Works], Vol. 18, p. 275, (Russian Edition)

initial stage in the study of the process, when the investigatory methodology was far from perfect and incapable of revealing the effect of external factors on the rate of radioactive decay. This corresponded precisely to that stage in the study of radioactivity when the atomic nucleus had not yet been identified as a source of radioactive emissions and when, to an even greater degree, factors of external stimulation of the nucleus were as yet unknown.. From the moment of the discovery of artificial radioactivity, assertions as to the invariability and independence of the radioactive process begin to conflict with scientifically established factual data.

In effect, there exists a process, which is well known and with which is associated the transformation of an element which exercises the most profound effect on the environment, but which, the advocates of this principle maintain, is itself dependent on nothing in nature and bears no relationship to the surrounding material world.

To assert the immutability and independence of the radioactive process, the constancy of its decay rate for all the conditions of the Earth, the Solar System, and even the galaxy, is also to declare that that which has never been created, which has never been generated can also decay. Obviously, decay is possible only by what has sometimes arisen or has sometimes been created. Clearly, the decay stage of radioactive elements must be preceded by the stage of their origination and creation, and the assertion of the constancy of decay is meaningless without its opposite -- the fact of becoming. The fact that radioactive decay is a general property of the elements found under terrestrial conditions may attest to the fact that under the evolutionary conditions of terrestrial matter a stage of becoming occurred, a stage of the formation of these radioactive elements, and that radioactive decay is a process which arose only in the subsequent developmental history of the Earth's matter.

Discoveries in the realm of atomic physics have overturned the dogma of the invariability and independence of the radioactive process and have affirmed anew the legitimacy of the principles of dialectical materialism.

/48

Lenin pointed out: "The destructibility of the atom, its exhaustibility, the variability of all the forms of matter and of its movement -- these have always been the undergirding of dialectical materialism."¹

Such are the principal criticisms of the principle asserting the constancy and independence of radioactive decay which we proposed in an article written in 1948 and published in 1951 [44]. One cannot fail to perceive the soundness of these remarks in the results of the radiometric determinations of recent years, which indicate the contingent significance of "absolute" dating, inasmuch as its data are grouped within a wide range of rock age complexes and pinpoint stages in the thermodynamic history of the crust rather than the absolute age of the rocks. The resultant data are of substantial (relative) importance in the study of the geological history of a region and the stratigraphic succession of geological formations, as determined on the basis of geological and biostratigraphic data. It would appear that in this respect an objective assessment of age data obtained by radiometrical techniques might be provided for the individual regions for which these data have been derived. As an example of such an assessment, particularly deserving of attention, we might cite that performed by A. A. Bogdanov for the Kola Peninsula, regarding whose pre-Cambrian formations numerous radiometric determinations of rock and mineral age have been carried out.

Bogdanov writes: "Experience in the development of the geology of the pre-Cambrian of the Baltic Shield indicates that in the discrimination of pre-Cambrian folded complexes very great importance attaches to the radiogeological data regarding the so-called absolute age of the rocks. At the same time, evidently, a consensus is also generally developing to the effect that in the study of metamorphic rocks radiological readings permit the determination of the time of occurrence of the latest metamorphic processes, but not the 'age' of the rock itself. Radiological determinations provide invaluable information on the most recent transformations in rock matter, caused by both metamorphic and dislocational processes" [48, p. 13].

/49

¹ V. I. Lenin, *Polnoye sobraniye sochineniy* [Complete Works], Vol. 18, p. 298 (Russian Edition)

Bogdanov concluded that radiological determinations make possible the determination of the geochronological position of very important dividing lines which are more than anything else the interfaces of adjacent tectonic complexes. However, the actual discrimination and isolation of these complexes must and can be accomplished only through the employment of the entire sum of the geological data characterizing them.

One cannot argue with this appraisal, although even here there is the remaining unclear aspect of the chronological significance of the dating of "very important dividing lines," as interfaces of "adjacent tectonic complexes." For with regard even to so important a "dividing line" as the maximum age of the Earth's crust, in a relatively short period radiometric determinations have furnished figures of 1.8, 2.5, 4.5, and finally 10 billion years [49]. The discrepancy of the last figure is obvious if one considers that the maximum possible age of the Earth has been fixed at 6 billion years. Bearing in mind that the paleontological and historico-geological methods "provide a firm foundation for the reconstruction of the historical past of our planet, and also for the compilation of geological charts reflecting the structure of the upper portions of the terrestrial crust," excessive infatuation with the figures of "absolute" chronology may lead to serious inconsistencies [50, p. 300]. In this connection it would seem important to stress the great significance of the following conclusion by V. V. Menner: "Adherence to the fundamental postulate of materialist dialectics regarding the need to study all natural processes in their interrelatedness and causality is possible only in the event of an overall solution of the problems confronting geology. The departure from this principle which can be seen in the efforts to utilize only one particular methodology, which is particularly typical of work being conducted abroad, results in immense harm to science" [50, p. 311].

2. A New Form of Nuclear Processes -- Processes Occurring Under the Effect Of Natural Radioactive Radiation

/50

The new and important discoveries in the study of nuclear processes which have come to light in recent decades provide a basis for an entirely fresh approach to the basic problems of geology and radiogeology and, preeminently, those directly relating to the study of the phenomenon of radioactivity

itself, natural processes in the nuclear transformation of elements, and their role in the changing elementary structure of terrestrial matter. Other affected areas may well be our knowledge of the Earth's history, along with our understanding of the geological processes of the thermal balance. Ever greater significance has been taken on by the problems of radiogeological research, in which the present state of the art has been outlined in papers by V. I. Baranov [51], G. V. Voytkovich [52], and others. Let us consider certain of these problems in the light of experimental data.

Changes in the elementary chemical and isotopic composition of the Earth's matter under the effect of natural radioactive radiation. Here we are not generally concerned with that change in the elementary and isotopic composition of elements which occurs as a result of the fact that, over time, radioactive elements decay, with no corresponding replenishment, causing the ratio of elements in terrestrial matter to vary. This is accompanied by a reduction in the specific content of radioactive elements, which in fact determines the overall directivity of these changes. In this respect, radioactive processes have been well studied, and it has been established that the evolution of the elementary composition of terrestrial matter evolves as a consequence of the very process of radioactive decay. These, however, are not the problems toward which our research has been directed. We have proposed [23] for consideration an entirely new problem: the variation in the elementary chemical and isotopic composition of terrestrial matter occasioned by natural radioactive radiation. What we have in mind here is the fact that radioactive emissions (alpha, beta, and gamma), which arise during the process of radioactive decay itself, possess sufficient kinetic energy to excite the nuclei of the irradiated elements and to cause them to decay. This formulation of the problem impinges on the established view of the radioactive process as one which is independent of the external conditions which exist at the present time on the Earth or which have ever existed in the course of its being. /51

Experimental data in nuclear fission point, however, to the possibility that nuclear processes may have transpired in this manner in terrestrial matter. Here reference is made, primarily, to experiments which have been conducted using natural radioactive radiation. It will be recalled that in

the first experiments in nuclear splitting, alpha-particles from a natural radioactive RC' radiator were employed. These experiments established that under the effect of alpha-particles from RC', possessing their own kinetic energy -- that is, with no artificially induced acceleration -- the atomic nuclei of nitrogen, boron, fluorine, sodium, phosphorous, neon, magnesium, silicon, sulphur, chlorine, argon, potassium, and, at a later date, beryllium and lithium were split.¹

For many years nuclear splitting was accomplished through the use of alpha-particles emitted by natural radioactive elements. In these fissions the alpha-particles were captured and protons were emitted by the decaying nuclei.

This is an important point, since at the present time atomic nuclei are split by means of particles accelerated in special apparatus and possessing energies of hundreds of megaelectron-volts and more -- that is, particles with energy levels unknown under the natural conditions of terrestrial matter. Of great significance to an understanding of many geological processes is the establishment of the fact that the nuclei of many chemical elements will decay under the effect of alpha and other particles formed as a result of natural radioactive decay and possessing the natural velocity that is proper to them.

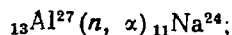
It should be observed that as early as 1934 many stable elements were definitively shown to have radioactive isotopes; to obtain these radioactive isotopes neutrons were used, the source of which was an ampoule containing beryllium powder and radium emanation. Thus, the neutrons were formed under the effect of radiation proceeding from a natural emitter. Radioactive substances were acquired with a fair degree of frequency: of sixty irradiated elements, forty became radioactive after neutron irradiation. These tests demonstrated that under the effect of neutrons not only light, but heavy elements as well become radioactive.

/52

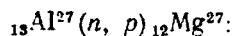
It has been established that the transformation of the nucleus which has captured the neutron may be accomplished in a variety of ways: in some

¹ Factual data indicating sources may be found in our work [23]; cf. also [53].

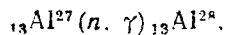
instances, with the emission of alpha-particles, for example



in others -- with the emission of protons

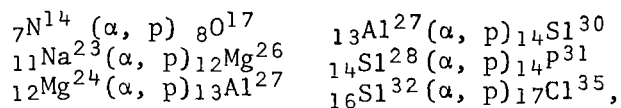


and in third cases, with direct neutron capture



where α is the designation of the alpha-particle -- helium nucleus with mass 4 and charge 2.

For many years "artificial" splitting of nuclei was conducted by means of alpha-particles emitted by natural radioactive elements. These reactions are well understood. By way of example, we cite several of the familiar nuclear reactions which occur under the influence of alpha-particles:



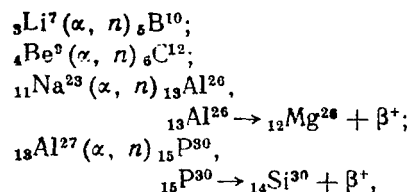
p is the designation of the proton-hydrogen nucleus.

Of the reactions cited above, particular interest attaches to the aluminum fission reaction, resulting in the flying out of a particle possessed of considerably greater kinetic energy than that of the alpha-particle under the effect of which the decay takes place. This fact indicates that alpha-particles act as a kind of "initiator" or exciter of nuclear forces.

/53

Therefore, experimental data have established that under the action of alpha-particles emitted by natural radioactive substances the nuclei of many light, widely encountered elements may be split.

At the present time it is well known that alpha-particles may give rise to decay accompanied by the emission not only of protons, but also of neutrons, in addition to other particles as well. Consider the reactions:



here β^+ is the designation of the positron.

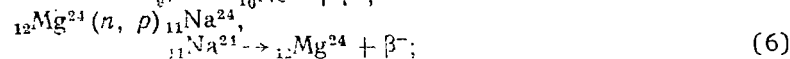
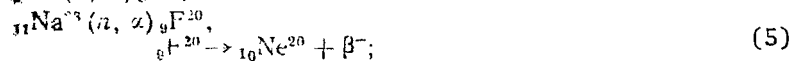
These reactions, transpiring under the effect of alpha-particles, are of interest to the problem under consideration in that the neutrons formed as a result of the decay exhibit sufficient kinetic energy to in turn cause the splitting of nuclei -- and of a significantly larger number of elements than through the agency of alpha-particles. It is known that neutrons will split even heavy nuclei, including those of the radioactive elements.

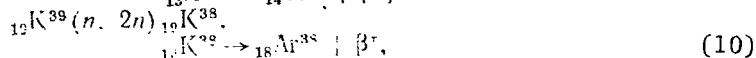
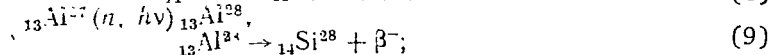
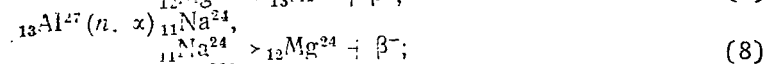
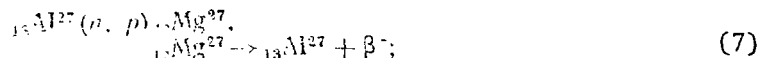
Since they lack any electrical charge, neutrons easily penetrate the nuclei of even heavy atoms possessing a large charge. The forces which prevent the charged alpha-particles and protons from penetrating the nucleus, have so little effect on the neutron that even those with very small kinetic energies operate in an extremely effective manner and give rise to fission.

In the case of reactions transpiring under the effect of neutrons, in each elementary act there may arise protons, alpha-particles, neutrons, or photons which, under the proper circumstances, may in turn cause nuclear fissions.

Given below are only a few of a large number of well known reactions which take place under the effect of neutrons:

/54





where β^{-} is the electron; $h\nu$ is the photon.

Fission occurs in the nuclei of virtually all elements under the effect of neutrons. Certain of these fissions are accompanied by fast neutrons with an energy of a megaelectron-volt and above, while numerous others take place more effectively through the agency of slow neutrons. It has been ascertained that neutrons with energies corresponding to the thermal velocities in the movement of matter are capable of producing numerous fissions. Slow neutrons are obtained as a result of the deceleration of fast neutrons. Every fast neutron, if it does not strike the nucleus when ejected, rapidly loses its velocity as a result of collisions and becomes a decelerated neutron. This neutron passes through the entire range of velocities, and, consequently, through the resonance level steps as well, at which, it will be recalled, neutron effectiveness is very high.

Analyzing these reactions, it is essential to call attention to several very significant properties in many of them.

Thus, reaction (1) represents the conversion, under the effect of a neutron, of conventional hydrogen into heavy hydrogen (deuterium); consequently, assuming the proper conditions, nature is the scene of a natural process in the accumulation of heavy water. Reaction (2) is of interest in that, as a result of the fission of lithium, tritium is obtained, which is an extremely effective particle for the production of nuclear fissions.

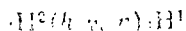
Reactions (5) through (10) are interesting because they cause the splitting of elements widely encountered in the natural state and are accompanied by the radioactive decay of the newly formed nuclei.

/55

Moreover, reaction (6) is typical of reactions in which the final product is identical with the initial: under the effect of the neutron, Mg^{24} becomes Na^{24} with the separation of a proton; as the result of radioactive decay accompanied by the separation of an electron, Na^{24} is transformed into Mg^{24} which is the basic element.

The K^{39} fission reaction is typical of a number of neutron-induced reactions in which one neutron is captured and two are ejected. This is an extremely important fact since it demonstrates the possibility that an accelerated decay process may develop under favorable conditions.

It should be noted that a splitting of the nucleus also occurs under the effect of photons -- that is, gamma-rays emitted by radioactive substances. Thus, we know that ThC'' gamma-rays have been used to split heavy hydrogen; these rays possess a kinetic energy of 2.62 MeV. The process is characterized by a deuteron splitting into a neutron and proton according to the scheme:



This fission also takes place under the action of RaC γ -rays whose kinetic energy is equal to 2.198 MeV.

Of paramount cognitive importance to an understanding of the conditions and factors which may affect the course of natural radioactive transformations are the data on the study of chain reactions. These data demonstrate that the factors which may influence the behavior of a natural radioactive process lie in the area of the formation of microparticles and in the combination of conditions propitious to the realization of nuclear transformations.

We know that the following parameters are essential to the development of a chain reaction: the mass of the radioactive substance, the form of the mass, the purity of the substance, the presence of neutrons, the presence of inhibitors (carbon, heavy water, beryllium, and others), although the reaction may occur at altogether normal temperatures and pressures.

Under the natural conditions in which radioactive decay processes take place, the presence of stray neutrons, formed as a result of the effect of

/56

cosmic rays, is not constant; also different are the possibilities that neutrons will be formed from the decay of radioactive elements. Similarly various are the combinations of favorable factors for the development of nuclear reactions.

Both the data cited above and much other known information on the fission of atomic nuclei effected under the action of nuclear particles with natural energies have opened up a new area of natural nuclear transformations -- the area of nuclear geochemistry. There is no doubt but that as a result of nuclear processes occurring under the effect of radio-radiation throughout the geological history of the Earth (measured in billions of years), changes have taken place in the elementary and isotopic composition of terrestrial matter. In this way, along with the already familiar factors in the evolution of the Earth's matter, such as the process of radioactive decay itself, the settling on the Earth of cosmic matter (meteoric remnants and cosmic dust), and space radiation, the isotopic composition is altered through the agency of natural radioactive emissions.¹

Geological factors affecting the behavior of natural radioactive processes. On the basis of experimental data, partially cited above, it may be considered established that the kinetic energy of radio emissions, as well as of the neutrons and protons generated under the effect of radioactive radiation, is sufficient to bring atomic nuclei into a state of excitation and to cause their decay.

Under natural conditions radioactive elements are found in different associations with other elements and in different quantitative ratios. Also different is the distribution of radioactive elements in the various envelopes of the Earth. Consequently, the nuclear process occasioned by the action of radioactive emissions with the natural energy proper to them take place with different intensity and with different decay products under different terrestrial conditions.

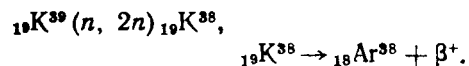
/57

The explanation of how nuclear processes occur in a definite specific instance of a natural concentration of some radioactive substance, what is the

¹ Nuclear transformations due to the effect of radioactive radiation have been acknowledged in works [54, 22].

intensity of these processes, what are their decay products -- all these questions pose new and as yet unresolved problems. At the present time, research into the yield of nuclear reactions, primarily of two-component systems, under the effect of accelerated particles is still in its infancy. Such research provides some material for an understanding of natural nuclear processes. However, with a view toward natural conditions, what are required in this context are direct investigations using natural radio-radiation. Under natural conditions the source of the emissions is *per se* extremely complex since there always exist in it particles of different energies, with the target for these particles not some homogeneous, isolated substance, but the natural multicomponent association of elements with different atomic weights and charges. The determination of the yield of reactions in this complex system constitutes a new and important problem. It is essential to note that similar new problems arise as soon as we begin to perceive the cognitive significance of already known experimental data in physics, as they apply to the geological area which is of interest to us.

On the possibility of an effect by geological conditions on the course of K^{39} nuclear transformations. From experimental data we know that, under the effect of fast neutrons, K^{39} decays according to the following scheme:



Two slow neutrons are formed as the result of this nuclear reaction. Since the fission of potassium requires fast neutrons, but its decay results in the formation of slow neutrons, under the conditions of potassium's isolated occurrence these slow neutrons will have no meaningful effect on the rate of its decay. On the other hand, if uranium is present together with the potassium, the effect of the slow neutrons emitted by the potassium as it decays will be different. We are aware that, under the effect of slow neutrons, U^{235} undergoes fission, emitting fast neutrons which may split into U^{238} and K^{39} . With the splitting of U^{238} , fast neutrons will also be ejected which are capable of splitting the K^{39} or, as the result of collision, of becoming slow

/58

neutrons capable of causing the fission of U^{235} , but U^{238} is transformed, under the effect of the slow neutrons, into U^{239} and causing its radioactive decay with beta-radiation. In the event of the splitting of potassium by fast neutrons, in each act of decay, as already mentioned, two slow neutrons will be ejected, which are in turn the splitters of the uranium.

It should be evident from this discussion that, whenever potassium and uranium are found together, the nuclear processes may take place with greater intensity than with the potassium subjected to the action of fast neutrons under isolated conditions.

There are reasons to believe that the behavior of nuclear processes, with potassium and uranium present together, may be influenced by the concentration and relative arrangement of the potassium and uranium atoms in the mineral, the size and form of the mineral itself, as well as the presence of impurities and their elementary composition. Bearing in mind the natural conditions under which these elements are found and the duration of these processes in the Earth's crust, defined in terms of billions of years, the results of these nuclear transformations may be of great importance in the evolution of terrestrial matter. The study of natural nuclear processes, with an eye toward the specific conditions under which the radioactive substances are encountered and the factors affecting the course of these processes, poses a new and vital problem in the understanding of terrestrial matter.

The effect of geological conditions on the fission of nuclei of heavy radioactive elements. In 1939 incontestable proof was obtained that when uranium is bombarded with neutrons, decay products are derived, among which Ba and La isotopes are present. It was also determined that similar decay occurs when thorium is bombarded by neutrons. /59

It is well recognized that when bombarded by neutrons, uranium splits into two approximately equal parts. There are voluminous data on fragments of this type. All the fission products are distributed into two groups: one with an atomic number ranging from 35 to 43 and with atomic weights from 82 to 100; the other with atomic numbers 51-57 and weights 127-150. Among the decay products included in the lighter group are Br, Kr, Rb, Sr, Y, Zr, Nb, Mo, and Te, with the heavier group including Sb, Te, Xe, Cs, Ba, La, and Ce.

Based on these experimental data, there is reason to assume that these elements are formed under natural conditions due to the splitting of uranium and thorium. Substantiating this view is the fact that in minerals containing uranium and thorium there are frequently present in small amounts rare earths and other elements encountered in the uranium and thorium fission product group.

Bearing in mind the variety of associations of uranium- and thorium- containing minerals with other elements under natural conditions, it is not hard to imagine the variety of transformation products arising from nuclear decay.

What are required are broad-based investigations into natural nuclear processes, looking toward the discovery of the general directivity of changes in the elementary and isotopic composition in various spheres of the Earth and under different conditions inherent in the natural concentrations of radioactive elements.

The possibility of high pressures affecting the radioactive properties of elements. Experimentation conducted in recent years on the high-pressure behavior of matter (on the order of hundreds of thousands of atmospheres) reveals that at these pressures the electron shells of the atom are deformed.¹ Concomitantly with this deformation, the shells draw closer to the nucleus of the atom, which inevitably causes a corresponding perturbation in the atomic nucleus as an equilibrium system. Under these conditions, the nucleus may capture the electrons located in the orbits closest to it, and there may occur, under conditions of an increasing hydrostatic compression of the elements, a neutralization of charges -- the merging of electrons and protons with the formation of neutrons. Experimental data indicates [56] that atoms deformed under a pressure of 100-200 thousand atmospheres, when the pressure is removed, may be restored and resume their normal state. In the case of extensive (deep) deformation, this restoration does not occur, possibly because of the neutralization of the atomic charges.

/60

¹ A theoretical validation for the possibility that any body may enter the metal state at high pressures may be found in works [55, 56].

TABLE 3. RESULTS OF THE DETERMINATION OF THE POTASSIUM
RADIOACTIVITY OF A NUMBER OF ROCKS FROM THE NORTHERN CAUCASUS

Designation of Rock and Locality	Age of Rock According to Geological Data	Potassium Activity in Pulses per 10 min.
Liparites, Baksan River (Tyrna-Auz region)	Upper Tertiary - post-Pliocene (1-60 million years)	140
Leucocratic granites, Tyrna-Auz region	Post-lower Jurassic (?)	119
Granites, Angamuga River (Uruk River basin)	Variscian	108
Upper Zgid granites (Ardon River basin)	Variscian	105
Rose granite, Eshkakon River (Kislovodsk region)	Middle Paleozoic - Caledonian	97
Quartz diorites, Tsea River (Ardon River basin)	Middle Paleozoic (?) Lower Paleozoic	95
El'dzhurtin red granites (Baksan River basin)	Post-lower Jurassic (?), Variscian	91
Rose granites of the Dakhov Massif (Belaya River)	Middle Paleozoic (?), Caledonian	84
Rose granites of the Indysh Massif (Kuban River basin)	Middle Paleozoic (?), Caledonian	58

These experiments point to the possibility of changes in the state of atoms in the bowels of the Earth where the hydrostatic compression increases as a function of depth, attaining values of millions of atmospheres and more. The manifestation, under these conditions, of elements with radioactive elements is of an importance that cannot be overstated. Without specially devised experimentation the investigation of this problem is not possible.

By way of substantiating the need for such research, we have cited below the results of our experimental work on the determination of the specific radioactivity of potassium taken from magmatic rock complexes of different age. This determination was made on small quantities of potassium salt (KCl) chemically derived from eruptive rock of various age (Northern Caucasus).

It will be observed in Table 3 that the greatest specific radioactivity (140 impulses in 10 min) was detected in the potassium taken from liparites near the Baksan River; which in terms of age are the youngest of those determined. The least specific radioactivity (58 impulses in 10 min) was shown by the potassium from specimens of the Indysh Granite Massif, whose geological age has been contingently established as ancient Paleozoic -- that is, it is the oldest of the rocks tested. All the remaining samples of nonsynchronous Northern Caucasus rocks occupy an intermediate specific-activity value midway between the liparites of the Baksan River and the Indysh granites.¹

The specific radioactivity in the potassium of nonsynchronous samples of magmatic rock may differ, as we see it, for two reasons.

In the first place -- and this seems the more likely explanation -- the potassium's specific radioactivity depends on the time which has elapsed since the formation of the magmatic rock. In light of the experimental data cited above on the deformation of the electron shells of atoms subject to high pressure, it seems possible that, with the magmatic focus developing under plutonic conditions, the atoms of the K^{40} isotope were excited, with a gradual transition of the potassium atoms from the excited to the normal state taking place after the magma had hardened and the rock formed. This process may be characterized by a lowering in the intensity of decay. Consequently, the older the rock, the lower the specific radioactivity of the potassium.

The other possible cause is a difference in the pressure and temperature at which the magma focus was formed. We know that magmatic focuses may be formed at various depths -- that is, under different pressures and

¹ According to existing views of the radioactive process as one which is independent of the environment, potassium salts from rocks of different ages ought to possess identical radioactivity, and it should be possible to assume that the discrepancies in the specific radioactivity of the potassium are caused by some error incurred in its determination. However, the practically three-fold variation in the potassium activity value disclosed by this experiment can scarcely be explained away by any such error, and it is conceivable that we are dealing here with the manifestation of new and extremely important radioactive properties in this element.

temperatures -- and it may be that in the case of a focus formation at great depths and high pressures and temperatures the atoms of the radioactive elements undergo more profound excitation, while at lesser pressures and temperatures their excitation is less intense, with this reflected in the intensity of radioactive decay and giving rise to a different specific radioactivity in the K^{40} .

It is possible, however, that the discrepancy in the potassium's specific radioactivity is caused by both of these factors.

In our view, specially tailored research might establish: do these factors affect the radioactive properties of the elements, and, if they do, what is the relationship of the radioactive decay process to these factors.

3. Radiogenic Heat and Its Significance in the Formation of the Geothermal Fields of the Lithosphere

Of great importance to the development of modern thinking regarding the Earth's thermal regime have been the investigations of V. I. Vernadskiy, V. G. Klopov [57], A. N. Tikhonov [58], Ye. A. Lyubimova [59], V. A. Magnitskiy [60], and others. In recent decades, substantial contributions to our understanding of the thermal regime of the terrestrial crust and of the laws governing the formation of its geothermal field have been made by: F. A. Makarenko, P. N. Kropotkin, N. I. Khitarov, P. F. Shvetsov, G. S. Gorshkov, Ye. A. Lyubimova, S. A. Kraskovskiy, A. M. Ovchinnikov, V. N. Dakhnov, D. I. D'yakonov, V. V. Ivanov, M. F. Belyakov, Sh. F. Mekhtiyev, G. M. Sukharev, A. A. Menyaylov, V. I. Vlodavets, V. S. Zhevago, V. A. Pokrovskiy, B. F. Mavritskiy, A. M. Bedcher, V. P. Runich, S. A. Dzhamalov, N. M. Florov, V. M. Nikolayev, A. I. Khrebtov, G. A. Chereminskiy, and many others. The results of these studies have been published in the transactions of the First [61] and Second [62] Conferences on Geological Research, as well as in the definitive compilation on thermal waters [63] and other works. These studies have made available a wealth of material on the problem of the distribution of geothermal fields¹ within the territory of the Soviet Union.

¹ By "geothermal fields" we understand segments of the Earth's crust having different heat flux values.

The observed distribution of geothermal fields in Soviet territory reveals characteristic peculiarities bespeaking their origination and formative circumstances. We might note that we are dealing here with geothermal fields located in the upper portion of the lithosphere, principally in the 0.5-5 km depth zone [64-69].

One such essential peculiarity consists in the locality of field distribution, with the fields encountered at all latitudes, from the polar areas to the southernmost regions of the country, with occurrences both in geosynclinal regions and foot hill depressions, as well as on platforms where they are associated with geological structures of different orders.

We note also that both the geothermal fields encountered in regions of recent volcanic activity, and the magma foci with which they are associated here, are similarly of a local character, a fact which points to a number of genetic causes and conditions which they share in common with geothermal fields situated outside these areas -- that is, outside the areas of recent vulcanism.

The wide distribution of high-temperature geothermal fields outside areas of young vulcanism (an example of which might be the fields of the Russian Platform, the West Siberian Plain, and others) attests to the fact that /64 it is not possible to reduce the heat sources which ensure the formation of geothermal fields to foci of magmatic activity, and that, apparently, these involve more general causes responsible for their origination.

It is important to note that sizable geothermal fields with high temperature values are unknown in areas distinguished by an abundance of crystalline and ancient metamorphic rock devoid of blanket-deposit formations, as well as in regions where the blanket deposit is negligible (Baltic Shield, Ukrainian Crystal Massif, and others).

Analysis of these particularities in the geothermal field distribution leads to a number of considerations on the causes, site, and condition of field formation.

The distribution observed in the geothermal fields cannot be explained by exogenic factors tied to a solar heat source, although it is known that solar

energy does play a decisive role in the thermal regime of the atmosphere, the surface hydrosphere, and the uppermost section of the Earth's solid shell. Nevertheless, according to available data, the effect of solar heat is felt at limited depth from the surface and -- a particularly important point -- its distribution here bears a zonal belt-like character.

Nor can this distribution in the fields be explained by the presence of plutonic (subcrust) heat sources, since such sources, were they to exist, would be capable of causing a kind of general thermal background over vast segments of the Earth's crust, or a certain overall background for the crust as a whole. One might admit that such deep-lying heat sources do exist and play some role in the formation of the Earth's general heat flux; but, evidently, the presence of such deep-seated foci of heat cannot be invoked to explain the local character observed in the distribution, within the terrestrial crust, of geothermal fields of different heat flux value, or their origination within the limited areas of one and the same geological structure.

Therefore, the observed heat field distribution cannot be explained either /65 by the flow of solar energy to the Earth or by the postulation of deep-lying heat sources within the Earth itself.

From the local distributional character of the geothermal fields it follows that the sources and factors responsible for their formation are also local in nature and that they should be sought in that portion of the lithosphere with which their occurrence is associated.

Obviously, the causes responsible for the origination of high-heat-flux thermal fields in the upper portion of the crust are to be found in the compositional peculiarities and occurrence circumstances of the geological formations of that same upper segment.

It will be evident that what is involved here is that portion of the Earth's crust which is most accessible to direct investigation and for which factual data are available regarding the material composition of rocks, their radioactive and thermophysical properties, and the circumstances of their occurrence.

It must be stressed that we do not exclude the possible formation of plutonic heat sources nor their importance to the generation of geothermal fields.

It has been pointed out above that rocks of plutonic origin contain radioactive elements, attesting to the possibility that magmatic foci [70] may have been formed in definite depth zones beneath the crust, which could also be the source of the ore solutions [71] that, under favorable tectonic conditions, penetrate into higher levels from the areas below the crust.

In the opinion of certain investigators, favorable physico-chemical conditions exist for the melting of magma at depths below the crust, below the Moho level, within the zone assigned to the Gutenberg line. At the present time the prevailing view is that "magma formation occurs at great depths -- from 20 to 80, 90, and even 150 km" [72, p. 185]. Rising up from this zone through deep fractures, the magma enters the crust and, after hardening, forms magmatic bodies. According to V. I. Smirnov, the formation of endogenic deposits is mainly due to internal forces of the Earth and is linked to the formation, introduction, and hardening of subterranean melts or magma [73]. A confirmation of the possible existence of this kind of mechanism in the formation of magmatic bodies is seen in those instances in which the products of magmatism are coordinate with deep fractures in the Earth's crust.

/66

An essential feature of the thermal anomalies so generated will be their spatial orientation along the fault lines. Without excluding sources of plutonic heat, the formation in the stratisphere of high-temperature geothermal fields can be satisfactorily explained by the accumulation of heat in the lithosphere itself.

On the basis of available data it may be assumed, without fear of major error, that of all known sources of heat in the crust the ones with the greatest significance for its upper portion are radioactive processes and chemical reactions: the first because of the high concentrations of radioactive substances in clastic rocks and especially in the clays normally

comprising the major portion of the geological sections of the upper lithosphere; the second -- chemical reactions -- because of the high content of organic matter in the upper portion of the lithosphere and the chemical process involved in the level fluctuations of surface and subsurface waters.

It would appear that all remaining heat sources -- mechanical, gravitational, and the others -- have no significant effect on the crust's upper portion. At the present time, based on the two principal heat sources mentioned, it is possible to make a quantitative determination of the heat released in connection with radioactive decay.

Relying on available data on the heat released in the radioactive decay process and on the content of radioactive elements present in rocks, as well as on data regarding the thermo-physical properties of rocks, thermal fluxes and the geothermal gradients of radiogenic heat can be calculated for each layer of a geological record, with these data used to establish zones and regions favorable to the formation of geothermal fields due to radiogenic heat. /67

Study of the properties of radioactive emissions and the rate of decay of radioactive elements has led to the determination [24] of the amount of heat released as these elements decay. This heat has been computed from measured energies of the alpha-, beta-, and gamma-rays emitted by the radioactive elements.

Also established, and today generally recognized, is the fact that acid rocks contain higher concentrations of such basic radioactive elements as uranium, thorium, and potassium than rocks of average acidity, while in the latter their content is greater than in the basic and ultrabasic rocks.

Regarding the sedimentary rocks, it has similarly been established that the content of the principal radioactive elements in the clays and shales is considerably higher than in the sandstones, but that in the latter it is greater than in the limestones.

Data on the content of radioactive elements in rocks provides a basis for calculating the amount of radiogenic heat released. At the present time, the content of radioactive elements in rocks comprising the upper portion of the

crust, immediately accessible to direct examination, has been more or less reliably determined.

It has been demonstrated that the primary mass of radioactive elements are concentrated in the upper shell of the Earth. This provides a basis for the assumption that the role of radiogenic heat in the formation and evolution of the crust must be enormous, particularly in the formation and distribution of the thermal fields situated within its uppermost portion. It is precisely in this region, the reader will recall, that the highest concentrations of radioactive substances are concentrated.

The available data support the belief that the primary source of the thermal flux observed on the Earth's surface (thought today to average 1.2^{-6} cal/cm²·sec) are the radioactive substances present in the terrestrial crust.

Similar information on the content of radioactive elements in rocks indicate that they are distributed in a nonuniform basis in geological complexes. There are also differences in the specific value of individual rock types, as characterized by varying radioactive content, in the structure of geological regions.

/68

On the basis of data regarding the content of radioactive elements in rocks, we have compared their distribution with the actual pattern of the thermal field distribution and geological structure of a number of regions [74]. The figures show that those concentrations of radioactive elements (uranium, thorium, their families, and potassium) which are normally encountered in rocks, release in decay a quantity of heat of such magnitude as to be able, in a relatively short period (geologically speaking), to heat the rock containing them to hundreds of degrees or even to melt it (Table 4).

The tabularized data show that the time required to heat granite to 200°C, given those quantities of radioactive elements which are normally contained in it, is set at approximately 5 million years, while for the clays a figure of some 6 million years is cited.

Under favorable conditions of occurrence, heat in rocks is generated rather quickly because of the decay in radioactive elements, and thermal fields together with individual thermal anomalies may be created in all

geological complexes (magmatic and sedimentary), including Upper Tertiary formations whose age is no less than 3-5 million years. However, it is essential to note that our calculations were made on the assumption that the total heat released in radioactive decay goes to the heating of the rock.

In actuality, because of the rocks' heat conductivity, a considerable portion of the heat leaves the site of its generation and is ultimately released into the surrounding air. Particularly favorable conditions for a major effluence of heat from the site of its generation arise whenever the surface complex of formations in a geological structure is represented by rocks having high heat conductance, as in the case of the exposure of granites, which release into the air a sizable portion of the heat generated within them.

Analysis of available data on the determination of the Earth's thermal flux leads to the conclusion that a methodology can be formulated for establishing this flux on a layer-by-layer basis according to the types of its sources. Central to this method is the thinking which regards geological formations as systems or unique thermodynamic complexes invested with definite thermal potentialities.

/70

These systems or complexes may be individual beds or massifs of rocks, their facies and formations, present in the structure of the crust and defined by specific thermophysical properties.

In qualitative terms, the heat issuing from various sources is identical and therefore it does not, *per se*, contain any attributes attesting to its origin. However, in the overall thermal flux it is quite possible, based on heat sources possessing quantitative and qualitative differences, to determine the specific significance of the heat which they release.

Of the numerous sources of subterranean heat commonly indicated for the Earth as a whole, radioactive decay and chemical reactions may be taken as the most important for the crust. The state of our knowledge permits an effort at a layer-by-layer computation of the specific value of the radiogenic heat alone in the general thermal flux.

TABLE 4. AVERAGE CLARK CONTENTS OF RADIOACTIVE ELEMENTS, THE HEAT THEY RELEASE, AND THE TIME REQUIRED TO HEAT THE ROCKS CONTAINING THEM TO 200°C

Rock types	U		Th		K		Total quantity of heat per 1 g of rock, $n \cdot 10^{-6}$ cal/yr	Required time for heating to 200°C, millions of years.
	Content, $n \cdot 10^{-6}$ g/g	Heat released, $n \cdot 10^{-6}$ cal/year	Content, $n \cdot 10^{-6}$ g/g	Heat released, $n \cdot 10^{-6}$ cal/year	Content, $n \cdot 10^{-6}$ g/g	Heat released, $n \cdot 10^{-6}$ cal/year		
Acid	4.5	3.33	16	3.2	0.028	0.76	7.30	4.7
Neutral	1.6	1.18	7	1.4	0.026	0.70	3.28	10.5
Basic	1.1	0.81	4	0.8	0.014	0.38	1.99	17.2
Ultrabasic	0.5	0.37	1.5	0.3	0.004	0.11	0.78	44.1
Limestones	1.4	1.04	1.8	0.36	0.003	0.08	1.48	27.0
Sandstones	3.0	2.22	10	2.0	0.012	0.32	4.54	8.8
Shales and Clays	4.0	2.96	11	2.2	0.032	0.86	6.02	6.1

Such a layerwise computation of radiogenic heat can be performed using the formula

$$Q_1 = Q_0 - Q_h,$$

where Q_1 is the flux at the foot of the layer; Q_0 is the thermal flux at the surface of the layer; Q_h is the entire quantity of heat released by the layer. The ratio between the flux Q , the geothermic gradient g , and the heat conduction factor λ is determined by the formula $Q = \lambda g$.

Using specific data on the content of radioactive elements in rocks and employing these formulae, we have computed the thermal flux of radiogenic heat for the granite massifs of the Baltic and Ukrainian shields, and also for the sedimentary complexes of the near-Caucasus and the West Siberian artesian basin (Figures 1-4).

On the basis of the resultant numerical values for the radiogenic heat flows, geothermic gradients and geothermic steps were plotted for the records. The radiogenic thermal flux calculations for the Ukrainian Shield, performed for depths of one, two, and three kilometers, show that the geothermic step at the first kilometer depth is 85.5, for the second -- 102.0, and for the third -- 125 m/degree. These data show good agreement with previously published information, based on actual temperature readings in shafts.

/71

For the Baltic Shield the geothermic step for radiogenic heat for the first kilometer equals 100, for the second -- 109.8, and for the third -- 120.5 m/degree. This figure for the geothermic step on the Baltic Shield is close to temperature values obtained by actual shaft readings.

Stratified computations for the radiogenic thermal flux carried out for the sedimentary complexes of the Northern near-Caucasus and the West Siberian Plain (Khanta-Mansiysk region) show good concordance with the findings of geothermic depth determinations derived from actual temperature measurements in shafts.

The data on the quantitative values of radiogenic heat and its distribution in the geological records of such basic structures of the Earth's crust as the Ukrainian and Baltic crystal shields, the near-Caucasus foothills

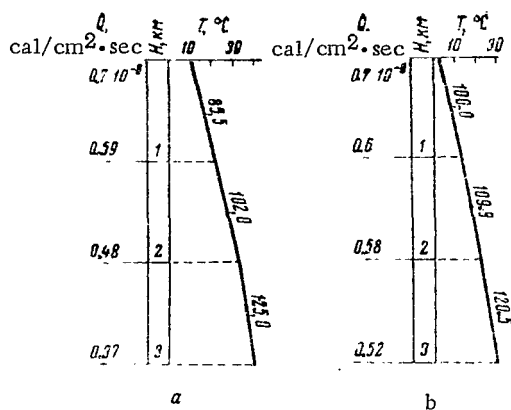


Figure 1. Graph Illustrating the Distribution of Radiogenic Heat in Granites of the Ukrainian Massif (a) and the Baltic Shield (b).

H , depth; Q , thermal flux; T , temperature. The numbers along the curve indicate geothermic steps in m/degrees

depression, and the West Siberian Platform disclose certain very essential peculiarities in these structures which are of importance to the formation of geothermal fields.

These data show that "open" structures, of the platform shield type, are unfavorable to the formation of high-temperature geothermal fields. The reason for this lies principally in the fact that these structures lack the blanket of argillaceous deposits which have a low heat conductance factor and function as a heat screen. Such structures are exemplified by the Ukrainian

and Baltic shields, in which, despite relatively high contents of radioactive elements (in comparison with the average clark contents for the crust as a whole), heat is not accumulated and the predominant feature is low geothermic gradients to great depths.

Altogether different conditions are obtained in regions exhibiting a well developed blanket of sedimentary formations in the composition of which clays are present in the upper portions of the records.

In sedimentary complexes the lowest step, as is evident from the example of the West Siberian artesian basin, occurs for an extensive argillaceous series (depth 350-1,050 m), which plays an enormous part in the formation of this basin, serving as an excellent insulating layer and powerful source of radiogenic heat. In the sedimentary complex the clays are characterized by the highest concentrations of radioactive elements.

/75

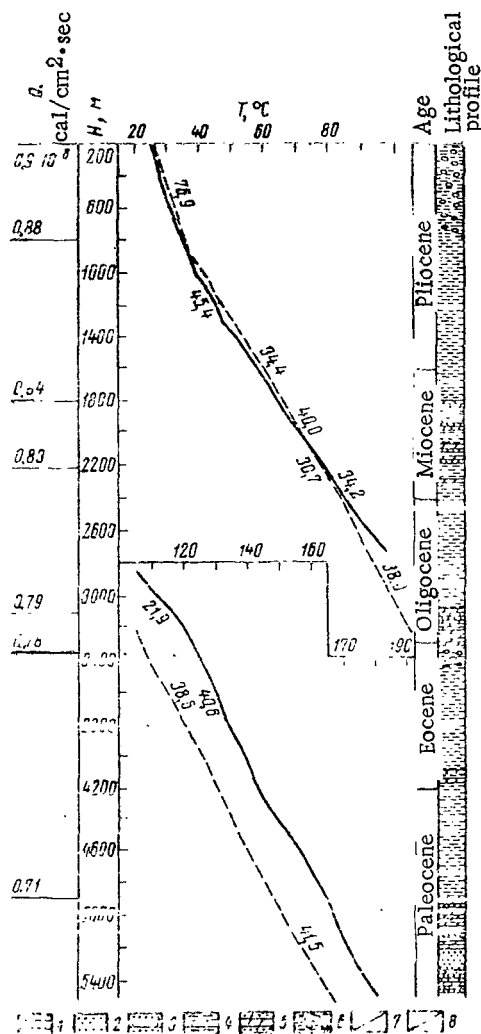


Figure 2. Collated Geothermogram of Tertiary Deposits in the Western near-Caucasus

1, clays; 2, sands and sandstones; 3, clays with interlayers of sands and sandstones; 4, clays with interlayers of marl; 5, clays with interlayers of sandstone and marl; 6, alternation of sands, sandstones, conglomerates, and clays; 7, heat distribution according to A. Z. Bedcher [75]; 8, radiogenic heat distribution according to data computed by N. S. Boganik. The numbers along the curves indicate geothermic steps in m/degrees.

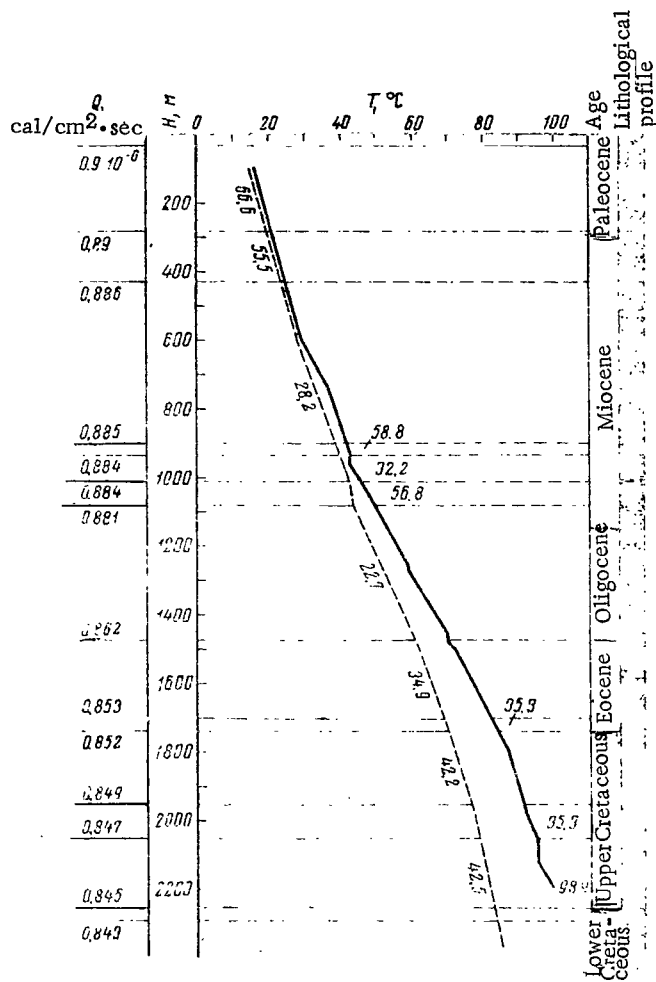


Figure 3. Graph Illustrating the Distribution of Radiogenic Heat for Shaft 1-P in the City of Nal'chik.

1, gravel; 2, argillaceous soil; 3, conglomerates; 4, sandstones; 5, clays; 6, fine-grained sands; 7, sandy clays; 8, marl; 9, limestones; 10, radio-genic heat distribution according to data computed by N. S. Boganik; 11, total heat distribution according to V. P. Runich [76]. The numbers along the curves indicate geothermic steps in m/degrees.

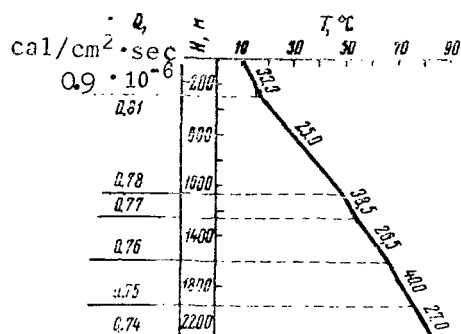


Figure 4. Graph Illustrating the Radiogenic Heat Distribution in the Sedimentary Complex of the West Siberian Platform.

The numbers along the curve indicate geothermic steps in m/degrees.

segment of the crust. Moreover, as this research shows, radiogenic heat plays an important role in the formation of thermal fields and in their distribution in the crust. According to approximate estimates, this heat accounts for 80% of the total thermal flux.

The establishment of the possibility of computing the value of the thermal flux of radiogenic heat for any segment of the lithosphere on the basis of radioactive and thermophysical properties opens up promising opportunities for revealing the conditions and time of formation of geothermal fields, the origination of magmatic foci, and for an understanding of the laws governing many geochemical processes, as well as the reconstruction of the thermal regimes for specific stages in the evolutionary history of the Earth's crust.

There is every reason to believe that studies into the role of radiogenic heat in the evolution of the crust and the formation of its structure will promote a more thorough comprehension of many of the processes and phenomena which take place in the lithosphere, and will provide a new and additional scientific basis toward an understanding of the laws underlying the processes of ore formation and the distribution of the mineral deposits to which they give rise.

Thus, as a result of high concentrations of radioactive elements and with propitious geological conditions in the constitution of the region, thermal fields of increased and high temperatures may be formed both outside young rock formations and outside areas of recent vulcanism.

The results of the investigations conducted point to the practical possibility of the layer-by-layer determination of the radiogenic thermal flux for any

The point of departure for such investigations will be the factual material which has already been collected regarding the radioactive and thermophysical properties of rocks, the distribution of geophysical and geochemical fields, along with data on the distribution of magmatic and sedimentary rock complexes and on the tectonic structure of individual segments of the Earth's crust.

/76

Particular importance attaches to the possibilities now coming to light, for the determination of the heat balances which existed in previous epochs, in any segment of the lithosphere -- balances which were caused by radiogenic heat.

By reconstructing geological records according to the formative state, for a given moment in history, of a given segment of the lithosphere, and by bearing in mind the content of radioactive elements in the rocks, we are able to calculate a layer-by-layer basis the geothermic gradient for that segment of the crust and to derive adequately substantiated data on the evolution of its thermal regime.

Such calculations may be of great importance in the prediction of concealed, hydrothermal-type deposits of nonferrous and rare metals formed in previous epochs under the appropriate thermodynamic conditions for the given crust segment.

CONCLUSIONS

/77

On the basis of this work the following conclusions and hypotheses may be drawn.

1. The "theory" of cyclic evolution, based on a constancy in the operation, on Earth, of the same forces and laws, is not in accord with available facts on the structure and evolution of the Earth's crust. In effect, the concept of cyclicity negates any evolution by reducing it to closed-cycle development, and thereby excludes the possibility of the emergence of new laws during the course of such evolution.

2. The manifestation and operation of the forces of gravity, magnetism, and of the nuclear forces vary in character on different celestial bodies, this being caused by the magnitude of the mass of the body in question and the combined manner in which these forces are displayed and operate in the specific conditions under which each such body exists. As a consequence, during the evolution of celestial bodies -- and, in particular, the Earth -- new laws emerge which determine the progressive movement in the evolution of the processes occurring on the planets and the historico-geological process on the Earth.

3. Progressivism in the evolution of geological processes is caused both by changes in the character with which fundamental forces and natural laws function, and by the fact that there takes place an uninterrupted evolution of terrestrial matter and development of the organic world, which world has had a substantial effect on the development of inorganic processes and has influenced in a variety of manners and surface of the Earth, the composition of rocks, and the geochemical processes transpiring in the crust, the hydrosphere, and atmosphere.

4. Geotectonic movements in the evolution of the crust have not shown a simultaneous or uniformly directional global character, but have occurred locally and in different manners. At each given natural-historic moment of time upheavals and subsidences have taken place in the Earth's crust as the consequence of specific factors in the geological development of the crust segment in question.

/78

5. Magmatic rocks and their associations, as also the sedimentary and metamorphic rocks, are products of the Earth's natural-historic evolution which have undergone changes in composition and structure in line with the general development of the crust and the evolution of its material composition.

6. The view of the radioactive decay process as a process which is constant and independent of external factors -- a concept which was formulated during the first stages in the study of radioactivity when the atomic nucleus had not yet been discovered -- is not in accordance with today's knowledge, which has established not only the fact itself of the atomic nucleus' existence, but also its structure and the factors which influence its state.

7. As the result of the analysis of experimental data on nuclear fission, conducted during the initial stages of nuclear research using alpha-radiation from natural radioactive elements, a new type of nuclear transformation, proceeding under natural conditions under the effect of radioactive emissions, has been discovered. Fundamental research is required to determine the significance of these emissions in the evolution of the elementary chemical and isotopic compositions of terrestrial matter.

8. Studies of the radioactivity of K^{40} provide a basis for the assumption that the potassium salts derived from nonsynchronous magmatic rocks possess different specific radioactivity. This points to new properties of K^{40} radioactivity and requires careful verification.

9. The available data on the deformation of the electron shells of the atom under high pressure support the supposition that in the plutonic regions of the Earth, where the pressure attains hundreds of thousands of atmospheres, the radioactive properties of elements are not manifested. A study of radioactive properties under high all-around compression may provide invaluable experimental material for an understanding of the Earth's heat regime and an answer to whether radioactive elements might be found in its depths.

/79

10. The local character in the distribution of thermal fields with higher temperatures is caused by factors which are also locally distributed and which appear collocationally with the fields themselves, that is, in the limits of the lithosphere.

11. A comparison of computed data on the distribution of radiogenic heat in geological structures with thermograms compiled on the basis of temperature readings in shafts indicates that the radiogenic heat formed in the upper portion of the lithosphere accounts for a considerable percentage of the total thermal flux.

12. It has been established that, under specific geological conditions, as the result of the generation of radiogenic heat in the lithosphere, thermal fields with higher and high temperatures may be formed.

13. The method of determining radiogenic heat on a layer-by-layer basis holds great promise for elucidating the conditions inherent in the formation of geothermal fields and the origination of magmatic foci, for understanding the laws governing the development of geochemical and ore-forming processes, and for reconstructing the thermal regimes of past epochs in the evolution of the Earth's crust.

1. Conference on Sedimentary Rocks. Reports. Issues 1-2. AN SSSR* Press, 1952-1955.
- 1a. *Puti i metody poznaniya zakonornostey razvitiya Zemli. Tezisy dokladov na ob'yedinennoy teoreticheskoy konferentsii filosofskikh (metodologicheskikh) seminarov nauchnykh uchrezhdeniy AN SSSR*, [Ways and Methods of Understanding the Laws Governing the Evolution of the Earth. Abstracts of Reports Presented at the Joint Theoretical Conference of Philosophical (Methodological) Seminars of Scientific Institutes of the Academy of Sciences of the USSR.] AN SSSR Press, 1963.
2. Augh, E., *Geologiya*, Vol. 1, 1914.
3. Boganik, N. S., "On the 'Theory' of Cycles in Contemporary Geology," *Sov. Geologiya*, No. 7, 1939.
4. Belousov, V. V., V. V. Menner and S. M. Simkin, Article on "Geology" in the *Bol'shaya Sovetskaya Entsiklopediya* [Large Soviet Encyclopedia], Vol. 10, 1952.
5. Peyve, A. V., "Horizontal Movements in the Earth's Crust and the Inheritance Principle," *Geotektonika*, No. 1, 1965.
6. Muratov, M. V., "The Principal Epochs of Folding and Metastages in the Evolution of the Earth," *Geotektonika*, No. 1, 1965.
7. Vinogradov, A. P. and A. B. Ronov, "The Evolution of the Chemical Composition of the Clays of the Russian Platform," *Geokhimiya*, No. 2, 1956.
8. Ronov, A. B., "Chemical Composition and the Conditions of Formation of Paleozoic Carbonaceous Strata on the Russian Platform (According to the Data of Lithologo-Geochemical Charts)," -- Transactions of the Geological Institute of the Academy of Sciences of the USSR, Issue 4, 1956.
9. Baranov, V. I., A. B. Ronov and K. G. Kunasheva, "On the Geochemistry of Dispersed Thorium and Uranium in the Clays and Carbonaceous Rocks of the Russian Platform," *Geokhimiya*, No. 3, 1956.
10. Khain, V. Ye., "The Evolution of the Earth's Crust and Possible Forms of its Relationship to Upper Mantle Processes," *Sov. Geologiya*, No. 1, 1964.
11. Ronov, A. B., "General Tendencies in the Evolution of the Composition of the Earth's Crust, the Ocean, and the Atmosphere," *Geokhimiya*, No. 8, 1964.
12. Yanshin, A. L., "The Tectonic Structure of Eurasia," *Geotektonika*, No. 5, 1965.
13. Yanshin, A. L., "The Actualism Principle and Problems in the Evolution of Geological Processes," In the Book: *Puti i metody poznaniya zakonornostey razvitiya Zemli. Tezisy dokladov na ob'yedinennoy teoreticheskoy konferentsii filosofskikh (metodologicheskikh) seminarov nauchnykh uchrezhdeniy AN SSSR*, [Ways and Methods of Understanding the Laws Governing the Evolution of the Earth. Theses of Reports Presented at the Joint Theoretical Conference of Philosophical (Methodological) Seminars of Scientific Institutes of the Academy of Sciences of the USSR]. AN SSSR Press, 1963.

* Translation Note: AN SSSR is the Academy of Sciences, USSR.

14. Strakhov, N. M., "Types of Climatic Zonality in the Post-Proterozoic History of the Earth and Their Importance to Geology," *Izv. AN SSSR, seriya geol.*, No. 3, 1960.
15. Strakhov, N. M., *Obrazovaniya osadkov v sovremennykh vodoyemakh*, [The Formation of Sediment in Contemporary Bodies of Water], AN SSSR Press, 1954.
16. Sidorenko, A. V., "Problems of the Sedimentary Geology of the Pre-Cambrian," *Vestn. AN SSSR*, No. 6, 1963.
17. Vologdin, A. G., *Zemlya i zhizn'*, [The Earth and Life], AN SSSR Press, 1963.
18. Tugarinov, A. I. and G. V. Voytkovich, *Geokhronologiya dokembriyskikh materikov*, [The Geochronology of Pre-Cambrian Continents], "Nedra" Press, 1966.
19. Kropotkin, P. N., "Paleomagnetism and its Importance to Stratigraphy and Geotectonics," *Izv. AN SSSR, seriya geol.*, No. 12, 1960.
20. Wilsen, R. L., "Does the Earth's Magnetism Reverse its Polarity?", *New Scientist*, Vol. 27, No. 456, p. 380, 1965.
21. Vernadskiy, V. I., *Izbrannyye sochineniya*, [Selected Works], Vol. 1, AN SSSR Press, 1964.
22. Baranov, V. I., "Radioactivity and Geology," In the book: *Vzaimodeystviye nauk pri izuchenii Zemli*, [The Interaction of Scientific Disciplines in the Study of the Earth], AN SSSR Press, 1963.
23. Boganik, N. S., "Nuclear Geochemistry -- A New Branch of Research," *Izv. AN SSSR, seriya geol.*, No. 6, 1953.
24. Voytkovich, G. V., *Radiogeologiya i yeye znacheniye v poznanii istorii Zemli*, [Radiogeology and its Importance to an Understanding of the Earth's History], Gosgeolizdat Press, 1956.
25. Vinogradov, A. P., *Khimicheskaya evolyutsiya Zemli*, [The Chemical Evolution of the Earth], AN SSSR Press, 1959.
26. Saukov, A. A., "Evolution of Factors in the Migration of Elements in Geological History," *Izv. AN SSSR, seriya geol.*, No. 5, 1961.
27. Trusov, Yu. P., "The Subject and Method of Geochemistry and Certain Problems in the Interaction of Sciences in the Present State of the Art in the Natural Sciences," In the book: *Vzaimodeystviye nauk pri izuchenii Zemli*, [The Interaction of Scientific Disciplines in the Study of the Earth], AN SSSR Press, 1963.
28. Shantser, Ye. V., "Contemporary Geology and its Place in the Modern Natural Sciences," [ibid.].
29. Daily, R., *Eruptive Rocks and the Depths of the Earth*, 1936.
30. Boganik, N. S., "On the Study of Magmatic Rocks," *Sov. Geologiya*, No. 25, 1947.
31. Kharley, P. M., *Vozrast Zemli*, [The Age of the Earth], Fizmatgiz, 1962.
32. Solov'yev, S. P., *Rasprostraneniye magmaticheskikh porod v SSSR*, [Magma Rock Distribution in the USSR], Gosgeolizdat Press, 1952.
33. Afanas'yev, G. D., "Magma Complexes and Geological Mapping," *Izv. AN SSSR, seriya geol.*, No. 5, 1953.
34. Kuznetsov, Yu. A., "Magma Formations," In the book: *Zakonomernosti razmeshcheniya poleznykh ispokayemykh*, [The Laws of the Distribution of Minerals], AN SSSR Press, 1958.
35. Afanas'yev, G. D., "The Basic Features in the Study of the Magmatism of the Greater Caucasus," *Izv. AN SSSR, seriya geol.*, No. 7, 1967.

36. Shipulin, F. K., *Istoriya formirovaniya intrusivnykh kompleksov i svyaz' s nimi orudneniya v Zyryanovskom i nekotorykh smezhnykh rayonakh Rudnogo Altaya*, [The History of the Formation of Intrusive Complexes and the Relation to Them of Mineralization in the Zyryanov and Certain Other Adjacent Regions of the Rudnoy Altay], Authors' abstracts of works by staff personnel of IGEM for 1958-1959. M., IGEM AN SSSR Press, 1960 (rotaprint).
- 36a. Shipulin, F. K., *Intruzii i rudoobrazovaniye (na primere Dashkesana)*, [Intrusions and Mineralizations (based on Dashkesan)], "Nauka" Press, 1968.
37. Lysle', Ch., *Osnovnyye nachala geologii*, [Fundamentals of Geology], Vol. 1-2, M., 1866.
38. Engel's, F., *Dialektika prirody*, [The Dialectics of Nature], Politizdat Press, 1955.
39. Vorontsev-Vel'yaminov, B. A., *Konechna li Vselennaya?*, [Is the Universe Finite?], "Leningr. gaz-zhurn. i kn." Press, 1947.
40. Abrikosov, A. A. and I. M. Khalatnikov, *Novyye svoystva elementarnykh chastits*, [New Properties of Elementary Particles], "Znaniye" Press, 1957.
41. Sviderskiy, V. I., "Dialectic Materialism on the General Properties in the Movement of Matter," In the book: *Filosofskiye voprosy sovremen-nogo ucheniya o dvizhenii v prirode*, [Philosophical Problems in Modern Doctrines Regarding Movement in Nature], LGU Press, 1962. /82
42. Vonsovskiy, S. V., *Priroda magnetizma*, [The Nature of Magnetism], "Znaniya" Press, 1964.
43. Miroshnichenko, L. I., "Cosmic Rays from the Sun," *Priroda*, No. 1, 1965.
- 43a. Vernadskiy, V. I., *Izbrannyye sochineniya* [Selected Works], Vol. 1, Moscow, AN SSSR Press, 1954.
44. Boganik, N. S., "Radioactive Decay and the Radioactive Method for the Absolute Dating of Rocks and Minerals," *Izv. AN SSSR, seriya geol.*, No. 4, 1951.
45. Chugayev, L. A., "Radioelements and the Periodic Law," *Prakticheskaya meditsina*, No. 11, 1915.
46. Bogoyavlenskiy, L. N. and A. A. Lomakin, "Experiments with Strong-Penetrating Radiation of Terrestrial Origin," *Izv. In-ta prikl. geofiziki*, Issue 3, 1927.
47. Petrzhak, K. A. and G. N. Flerov, "The Spontaneous Fission of Uranium," *ZhETF*, Vol. 10, Issue 9-10, 1940.
48. Bogdanov, A. A., "On the Tectonic Articulation of the Pre-Cambrian Formations of the Foundation of the East European Platform," *Vestn. Moskovsk. un-ta. Geologiya*, No. 1, 1967.
49. Tugarinov, A. I., "Methods for the Absolute Dating of Rocks and Geochronology," In the book: *Sovetskaya nauka i tekhnika za 50 let. Razvitiye nauk o Zemle v SSSR*, [Fifty Years of Soviet Science and Technology. The Development of the Earth Sciences in the USSR], "Nauka" Press, 1967.
50. Menner, V. V., "The Role of Biostratigraphy in Geological Research," In the book: *Vzaimodeystviye nauk pri izuchenii Zemli*, [The Interaction of Scientific Disciplines in the Study of the Earth], AN SSSR Press, 1963.
51. Baranov, V. I., *Radiometriya*, [Radiometry], AN SSSR Press, 1955.

52. Voytkovich, G. V., *Problemy radiogeologii*, [Problems of Radiogeology], Gosgeolizdat Press, 1961.
53. Kurchatov, I. V., "The Splitting of the Atomic Nucleus," *Problemy novoy fiziki* [Problems of the New Physics], Issue 2, L.-M., ONTI, 1935.
54. Vinogradov, A. P., *Osnovnyye problemy radiochemii*, [The Basic Problems of Radiochemistry], AN SSSR Press, 1959.
55. Kapustinskiy, A. F., "On the Theory of the Earth," In the book: *Voprosy geokhimii i mineralogii*, [Problems of Geochemistry and Mineralogy], AN SSSR Press, 1956.
56. Vereshchagin, L. F., "Miracles of High-Pressure Physics," *Pravda*, 1 March 1964, No. 61.
57. Khlopov, V. G., "Radioactivity and the Earth's Heat Regime," *Izv. AN SSSR, seriya geogr. i geofiz.*, No. 2, 1937.
58. Tikhonov, A. N., "On the Effect of Radioactive Decay on the Temperature of the Earth's Crust," *Izv. AN SSSR, seriya geogr. i geofiz.*, No. 3, 1937.
59. Lyubimova, Ya. A., "The Thermal History of the Earth and Its Geophysical Consequences," *Transactions of the First All-Union Conference on Geothermal Research in the USSR*, Vol. 1, AN SSSR Press, 1959.
60. Magnitskiy, V. A., *Osnovy fiziki Zemli*, [Fundamentals of the Physics of the Earth], Gosgeolizdat Press, 1953.
61. Problems of Geothermy and the Practical Use of the Earth's Heat, -- *Transactions of the First All-Union Conference on Geothermal Research in the USSR*, Vol. 1, AN SSSR Press, 1959; Vol. 2, 1961.
62. Geothermic Investigations and the Use of the Earth's Heat. *Transactions of the Second All-Union Conference on Geothermal Research in the USSR*, (in two books). "Nauka" Press, 1966 and 1967.
63. *Termal'nyye vody SSSR i voprosy ikh teploenergeticheskogo ispol'zovaniya*, [Thermal Waters of the USSR and Problems of the Use for Heat Energy], Edited by F. A. Makarenko. AN SSSR Press, 1963.
64. Makarenko, F. A., B. G. Polyak and Ya. B. Smirnov, "The Geotemperature Field on Soviet Territory," In the book: *Geologicheskkiye rezul'taty prikladnoy geofiziki. Mezhdunarodnyy geologicheskiiy kongress. XXIII sessiya. Doklady sovetskikh uchenykh*, [The Geological Results of Applied Geophysics. International Geological Congress. XXIII Session. Reports of Soviet Scientists], "Nauka" Press, 1968.
65. Lyubimova, Ye. A., "The Relation of the Thermal Flux Distribution to Tectonic Structures," [ibid.].
66. Aliyev, S. A. and Sh. F. Mekhtiyev., "Some Problems in the Geothermics of the Caucasus," [ibid.].
67. Vasil'yev, Yu. M., D. I. D'yakonov and M. M. Charigin, "The Geothermy of the Plutonic Depths of the Caspian Depression Based on Drilling Data from the Aralsor Superdeep Shaft," [ibid.].
68. Makarenko, F. A., "Temperature Distribution Chart for the Base of the Platform Sedimentary Blanket of Soviet Territory," in the book: *Regional'naya geotermiya i raspredeleniye termal'nykh vod SSSR*, [Regional Geothermy and the Distribution of Thermal Waters in the USSR], "Nauka" Press, 1967.
69. Sukhazev, G. G., S. V. Vlasova and Yu. G. Taranukha, "The Thermal Flux of the Greater Caucasus," *Doklady AN SSSR*, Vol. 177, No. 4, 1966.

70. Gorshkov, G. S., "Vulcanism and the Upper Mantle," In the book: *Problemy vulkanizma*, [Problems of Vulcanism], Petropavlovsk-Kamchatskiy Press, 1964.
71. Vol'fson, F. I., V. I. Kazanskiy, N. P. Lavetov, L. I. Lukin, B. I. Rybalov, Ye. P. Sonyushkin and L. V. Khoroshilov, "The Basic Features in the Geology of Hydrothermal Uranium Ore Fields and Deposits," In the book: *Geologiya gidrotermal'nykh uranovykh mestorozhdeniy*, [The Geology of Hydrothermal Uranium Deposits], "Nauka" Press, 1966.
72. Menyaylov, A. A., "Vulcanology," In the book: *Razvitiye nauk o Zemle v SSSR*, [The Development of Earth Sciences in the USSR], "Nauka" Press, 1967.
73. Smirnov, V. I., "The Geology of Ore Deposits," [ibid].
74. Boganik, N. S., "The Role of Radiogenic Heat in the Formation of Geothermal Fields," In the book: *Geotermicheskiye issledovaniya i ispol'zovaniye tepla zemli*, [Geothermic Research and the Exploitation of the Earth's Heat], "Nauka" Press, 1966.
75. Bedcher, A. Z., "Description of the Geothermic Gradient in the Kuban Oil Fields and the Application of Thermic Research to Solve Petroleum Industry Problems," -- *Transactions of the First All-Union Conference on Geothermal Research in the USSR*, Vol. 1, AN SSSR Press, 1959.
76. Runich, V. P., "Geothermic Conditions of the North Eastern Monoclinial Fold of the Greater Caucasus within the Kabardino-Balkar Autonomous Soviet Socialist Republic and Certain Problems Regarding the Interpretation of Geothermic Data," [ibid.].

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE \$300

FIRST CLASS MAIL

POSTAGE AND FEES PAID
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION



021 001 C1 U 13 720211 S00903DS
DEPT OF THE AIR FORCE
AF WEAPONS LAB (AFSC)
TECH LIBRARY/WLOL/
ATTN: E LOU BOWMAN, CHIEF
KIRTLAND AFB NM 87117

POSTMASTER: If Undeliverable (Section 153
Postal Manual) Do Not Return

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

— NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS:
Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Technology Surveys.

Details on the availability of these publications may be obtained from:

**SCIENTIFIC AND TECHNICAL INFORMATION OFFICE
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C. 20546**